GUIDE FOR CERTIFICATION OF

FRP HYDROCARBON PRODUCTION PIPING SYSTEMS

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July 2011 consolidation includes:

- November 2010 version plus Corrigenda/Editorials

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Foreword

This Guide specifies the ABS requirements for the certification of offshore pipes and piping components that are made of fiber reinforced plastics (FRP). Included are the requirements for design, manufacturing, construction, testing and survey during and after construction for the FRP pipes and piping components used in offshore topside modules. The requirements for piping components made of thermoplastic materials, such as polyvinyl chloride (PVC), commonly designed for minor applications, such as drainage, are intentionally excluded due to its limited usage. The significant enhancements in this Guide are made to the design considerations and the survey requirements for FRP pipes and piping components. More specific testing requirements are also provided for clarification purposes.

The requirements presented in this Guide are based on existing methodologies and common practices that are deemed to provide an adequate level of safety. Other technological approaches that can be proven to produce an equivalent level of safety will also be considered as an alternative to those given herein.

This Guide is applicable to the certification of topside FRP pipes and piping components for which applications or contracts for certification are received on or after 1 May 2005. This Guide supersedes the requirements on FRP piping installations specified in Appendix 1, "Plastic Pipe Installations," of the ABS *Guide for Building and Classing Facilities on Offshore Installations* (ABS *Facilities Guide*) and is to be used in conjunction with other parts of the ABS *Facilities Guide*.

GUIDE FOR CERTIFICATION OF

FRP HYDROCARBON PRODUCTION PIPING SYSTEMS

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SECTION 1 Scope and Conditions of Certification

1 Applicability

This Guide specifies the technical documentation and provides guidelines for design, manufacturing, installation and maintenance of offshore fiber reinforced plastic (FRP) piping installations used in offshore topside modules. The principal objectives are to specify the minimum requirements for certification and continuance of certification by ABS. Pipes and piping components made of fiber reinforced plastics (FRP), which are thermosetting plastic materials with reinforcement, may be used in piping installations referred to in Section 2, Table 3, subject to compliance with the requirements specified in this Guide.

In this document, the term "certification" indicates that an FRP piping installation has been designed, manufactured, installed and surveyed in compliance with the existing Rules, Guides or other acceptable standards.

The continuance of certification is dependent on the fulfillment of requirements for surveys after construction.

This Guide supersedes the requirements for FRP piping installation specified in Appendix 1, "Plastic Pipe Installations," of the ABS *Guide for Building and Classing Facilities on Offshore Installations* (ABS *Facilities Guide*), and is to be used in conjunction with other parts of the ABS *Facilities Guide*.

1.1 Process

The Certification process consists of:

a) The development of Rules, Guides, standards and other criteria for the design and construction of pipes and piping components

b) The review of design and survey during and after construction to verify compliance with such Rules, Guides, standards or other criteria

c) The issuance of certificates when such compliance has been verified.

The Rules, Guides and standards are developed by ABS staff and passed upon by committees made up of manufacturers, naval architects, marine engineers, builders, engine builders, steel makers and by other technical, operating and scientific personnel associated with the worldwide maritime and offshore industry. Theoretical research and development, established engineering disciplines, as well as satisfactory service experience are utilized in their development and promulgation. ABS and its committees can act only upon such theoretical and practical considerations in developing Rules, Guides and standards.

1.3 Certificates and Reports

Plan review and surveys during and after construction are conducted by ABS to verify to itself and its committees that the pipe and piping components are in compliance with the Rules, Guides, standards or other criteria of ABS and to the satisfaction of the attending Surveyor. All reports and certificates are issued solely for the use of ABS, its committees, its clients and other authorized entities.

1.5 Representations as to Certification

Certification is a representation by ABS as to the fitness of the pipe or piping component for a particular use or service in accordance with its Rules, Guides and standards. The Rules, Guides and standards of the American Bureau of Shipping are not meant as a substitute for the independent judgment of professional designers, naval architects, marine engineers, owners, operators, masters and crews, nor as a substitute for the quality control procedures of builders, steel makers, suppliers, manufacturers and sellers of marine materials, machinery or equipment.

ABS represents solely to the Manufacturer, Operator or other client of ABS that when certifying it will use due diligence in the development of Rules, Guides and standards and in using normally applied testing standards, procedures and techniques as called for by the Rules, Guides, standards or other criteria of ABS for the purpose of issuing and maintaining certification. ABS further represents to the Manufacturer, Operator or other client of ABS that its certificates and reports evidence compliance only with one or more of the Rules, Guides, standards or other criteria of ABS in accordance with the terms of such certificate or report. Under no circumstances whatsoever are these representations to be deemed to relate to any third party.

1.7 Scope of Certification

Nothing contained in any certificate or report is to be deemed to relieve any designer, builder, Operator, Manufacturer, seller, supplier, repairer, other entity or person of any warranty express or implied. Any certificate or report evidences compliance only with one or more of the Rules, Guides, standards, or other criteria of the American Bureau of Shipping and is issued solely for the use of ABS, its committees, its clients, or other authorized entities. Nothing contained in any certificate, report, plan or document review or approval is to be deemed in any way a representation or statement beyond those contained in 1/1.5. The validity, applicability and interpretation of any certificate, report, plan or document review are governed by the Rules, Guides, and standards of the American Bureau of Shipping who shall remain the sole judge thereof. ABS is not responsible for the consequences arising from the use by other parties of the Rules, Guides, standards or other criteria of the American Bureau of Shipping, without review, plan approval and survey by ABS.

3 Documents to be Submitted

3.1 General *(2011)*

For certifying FRP piping installations according to this Guide, the documentation submitted to ABS is to include plans, reports, calculations, drawings and other documentation necessary to demonstrate the adequacy of the design of the FRP piping installations. Specifically, required documentation is to include the items listed in this Section.

The documentation is generally to be submitted electronically to ABS. However, hard copies will also be accepted.

All plan submissions originating from manufacturers are understood to be made with the cognizance of the main contracting party. A fee may be charged for the review of plans that are not covered by the contract of certification.

3.3 System Plans

The following plans, whenever applicable to FRP piping installations, are to be submitted for review:

- Propulsion machinery space arrangement, including locations of fuel oil tanks
- Booklet of standard details
- Ballast system
- Bilge and drainage systems
- Boiler feed water and condensate systems
- Compressed air system
- Cooling water systems
- Exhaust piping (for boilers, incinerators and engines)
- Fixed oxygen-acetylene system
- Fuel oil systems, including storage tanks, drip trays and drains
- Helicopter refueling system, fuel storage tank and its securing and bonding arrangements
- Hydraulic and pneumatic systems

- Lubricating oil systems
- Sanitary system
- Sea water systems
- Vent, overflow and sounding arrangements
- Steam systems
- Steam piping analyses
- Tank venting and overflow systems
- All FRP piping installations not covered above

3.5 Contents of System Plans

FRP piping installation plans are to be diagrammatic and are to include the following information:

- Types, sizes, materials, construction standards and pressure and temperature ratings of piping components other than pipes
- Materials, outside diameter or nominal pipe size and wall thickness or schedule of pipes
- Design pressure and design temperature, test pressure
- Maximum pump pressures and/or relief valve settings
- Flash point of flammable liquids
- Instrumentation and control
- Legend for symbols used

3.7 Booklet of Standard Details

The booklet of standard details, as indicated in 1/3.3, is to contain standard practices to be used in the construction of the offshore installation, typical details of such items as bulkhead, deck and shell penetrations, welding details, pipe joint details, etc. This information may be included in the system plans, if desired.

3.9 Material Specifications

Documentation for all materials of the major components of FRP piping installations is to indicate that the materials satisfy the requirements of the pertinent specifications and standards. Material tests, if required, are to be performed to the satisfaction of ABS.

3.11 Design Data and Calculations

Information is to be submitted for the FRP piping installations that describes the material data, models and variability, long-term degradation data and models, methods of material system selection, analysis and design that were employed in establishing the design. The estimated design life of the FRP piping installations is to be stated. Where model testing is used as the basis for a design, the applicability of the test results are to depend on the demonstration of the adequacy of the methods employed, including enumeration of possible sources of error, limits of applicability and methods of extrapolation to full-scale data. It is preferable that the procedures be reviewed and agreed upon before material and component model testing is performed.

Calculations are to be submitted to demonstrate the adequacy of the proposed design and are to be presented in a logical and well-referenced fashion, employing a consistent system of units.

3.13 Test Reports

Test reports including procedures for and records of the testing as required in this Guide for the FRP piping installation are to be submitted. The test records are, as a minimum, to include an accurate description of the scope of tests, the subjects being tested, the setup of testing facilities, the methods and procedures of tests, the test results and the reasons for and disposition of any failures during a test. Records of tests are also to contain the names of the Owner and the test contractor, the date, time and test duration.

3.15 Installation Manual

A manual is to be submitted describing procedures to be employed during the installation of FRP piping installations. It is also to demonstrate that the methods and equipment used to meet the specified requirements. The qualification of the installation manual is to include procedures related to:

- Quality assurance plan and procedures
- Procedures and methods to evaluate impact and installation damage tolerance
- Nondestructive testing procedures
- Repair procedures to be followed should any damage occurred during installation
- System pressure test procedures and acceptance criteria
- Electric conductivity test procedures and acceptance criteria (as applicable)

3.17 Operations Manual

An operations manual is to be prepared to provide a detailed description of the operating procedures to be followed for expected conditions. The operations manual is to include procedures to be followed during start-up, operations, shutdown conditions and anticipated emergency conditions. This manual is to be submitted to ABS for record and file.

3.19 Maintenance Manual

A maintenance manual providing detailed procedures for how to ensure the continued operating suitability of the FRP piping installation is to be submitted to ABS for approval. Complete records of inspections, maintenance and repairs of FRP piping installations are to be provided for ABS.

3.21 Additional Documentation

When certification under the other regulation described in Chapter 1, Section 6 of the ABS *Facilities Guide* is requested, submission of additional documentation may be required.

5 Survey, Inspection and Testing

5.1 General

5.1.1 Scope

This Subsection pertains to inspection and survey of FRP piping installations at different phases, including:

- Manufacturing
- Installation
- Testing after installation

The phases of manufacturing covered by this Subsection include fabrication of FRP pipes and bonds, pressure test, fire endurance test, flame spread test, exterior corrosion barrier test and electrical conductivity test, as applicable. The phases of installation include preparation, transportation, installation, system pressure test, electric conductivity test, as applicable, and survey of the as-built installation. The post-installation phase includes survey for continuance of certification, accounting for damage, failure and repair.

5.1.2 Quality Control and Assurance Program

A quality control and assurance program compatible with the type, size and intended functions of the FRP piping installation is to be developed and submitted to ABS for review. The quality control and assurance program, as appropriate, is to consist of methods and procedures for evaluating FRP piping installation performance, including static internal pressure, elevated temperature, erosion resistance, electric conductivity and fire performance properties, as well as optional vessel motion, water, impact and low temperature. ABS will review, approve and, as necessary, request modification of this program. The Operator and Manufacturer are to work with ABS to establish the required hold points on the quality control program to form the basis for all future inspections at the fabrication yard and surveys of the FRP piping installations. If required, Surveyors may be assigned to monitor the manufacturing of FRP piping installations and assure that competent personnel are carrying out all tests and inspections specified in the quality control program. It is to be noted that the monitoring provided by ABS is a supplement to and not a replacement for inspections to be carried out by the Operator or Manufacturer.

5.1.3 Access and Notification

During manufacturing and installation, ABS representatives are to have access to FRP piping installations at all reasonable times. ABS is to be notified as to when and where the FRP piping installation may be examined. If ABS finds occasion to recommend repairs or further inspection, notice will be given to the Operator or Manufacturer or their representatives.

5.1.4 Identification of Materials

The Manufacturer is to maintain a data system of material for FRP piping installations. Data concerning place of origin and results of relevant material tests are to be retained and made readily available during all stages of manufacturing, installation and after-installation testing.

5.3 Inspection and Testing in Manufacturing Phase

5.3.1 Material Quality

The physical properties of FRP and its raw materials are to be consistent with the specific application and operational requirements of FRP piping installations. Suitable allowances are to be added for possible degradation of the physical properties in the subsequent installation and operation activities. Verification of the material quality is to be done by the Surveyor at the manufacturing plant, in accordance with the requirements of this Guide. Alternatively, materials manufactured to recognized standards or proprietary specifications may be accepted by ABS, provided such standards give acceptable equivalence with the requirements of this Guide.

5.3.2 Manufacturing Procedure Specification and Qualification

A manufacturing specification and qualification procedure is to be submitted for acceptance before production start. The manufacturing procedure specification is to state the type and extent of testing, the applicable acceptance criteria for verifying the properties of the materials and the extent and type of documentation, record and certificate. All main manufacturing steps from control of received raw material to shipment of finished FRP piping, including all examination and checkpoints, are to be described. ABS will survey formed FRP piping installations for their compliance with the dimensional tolerances, chemical composition and mechanical properties required by the design.

5.3.3 Nondestructive Testing

A system of nondestructive testing is to be included in the manufacturing specification of FRP piping installations. The minimum extent of nondestructive testing is to be in accordance with a recognized design code. All nondestructive testing records are to be reviewed and approved by ABS. Additional nondestructive testing may be requested if the quality of manufacturing is not in accordance with industry standards.

5.3.4 Manufacturing Records

A data book of the record of manufacturing activities is to be developed and maintained so as to compile as complete a record as is practicable. The pertinent records are to be adequately prepared and indexed in order to assure their usefulness, and they are to be stored in a manner that is easily recoverable.

The manufacturing record is to include, as applicable, the following:

- Manufacturing specification and qualification procedures records
- Material trace records
- Training and certification of workforce personnel
- Fabrication specifications
- Structural dimension check records
- Records of completion of items identified in the quality control program
- Assembly records
- Pressure testing records
- Fire endurance testing records
- Flame spread testing records
- Electrical conductivity testing records
- Coating material and external corrosion testing records
- Nondestructive testing records
- Marking, packing, handling and transportation records

After manufacturing, these records are to be retained by the Operator or Manufacturer for future reference. The minimum time for record retention is not to be less than the greatest of the following:

- Warranty period
- Time specified in manufacturing agreements
- Time required by statute or governmental regulations

5.5 Inspection and Testing during Installation

5.5.1 Specifications and Drawings for Installation

The specifications and drawings for installation are to be detailed and prepared giving the descriptions of and requirements for the installation procedures to be employed. The requirements are to cover the final design, verification and acceptance criteria for installation, as well as system pressure test, integrity of FRP piping installations, fire protection coatings and electric conductivity test. The drawings are to be detailed enough to demonstrate the installation procedures step-by-step. The final installation results are to be included in the drawings.

5.5.2 Installation Manual

Qualification of installation manual is specified in 1/3.15 of this Guide.

5.5.3 Testing After Installation

System pressure test after installation, as well as fire protection coating and electric conductivity test, as applicable, are to be conducted to verify that requirements specified in this Guide are satisfied.

5.5.4 Final Inspection

A final inspection of the installed FRP piping installation is to be completed to verify that it satisfies the approved specifications used in its manufacturing and the requirements of this Guide.

5.5.5 Inspection for Special Cases

Portions of the FRP piping installation may require inspection after the occurrence of any conditions that might adversely affect the stability, structural integrity or safety of the FRP piping installation. Damage that affects or may affect the integrity of the FRP piping installation is to be reported at the first opportunity by the Operator for examination by ABS. All repairs deemed necessary by ABS are to be carried out to their satisfaction.

5.5.6 Notification

The Operator is to notify ABS on all occasions when parts of FRP piping installations not ordinarily accessible are to be examined. If at any visit a Surveyor should find occasion to recommend repairs or further examination, this is to be made known to the Operator immediately in order that appropriate action may be taken.

5.7 Conditions for Surveys after Construction

5.7.1 Damage, Failure and Repair

5.7.1(a) Examination and Repair. Damage, failure, deterioration or repair of the installation or its elements, which affects certification, is to be submitted by the Owners or their representatives for examination by the Surveyor at the first opportunity. All repairs found necessary by the Surveyor are to be carried out to his satisfaction.

5.7.1(b) Repairs. Where repairs to FRP piping installations or elements connected thereto, which may affect certification, are planned in advance to be carried out, a complete repair procedure, including the extent of the proposed repair and the need for Surveyor's attendance, is to be submitted to and agreed upon by the Surveyor reasonably in advance. Failure to notify ABS in advance of the repairs may result in suspension of certification until such time as the repair is redone or evidence is submitted to satisfy the Surveyor that the repair was properly carried out.

The above is not intended to include maintenance and overhaul in accordance with recommended manufacturer's procedures and established practice and which does not require ABS approval. However, any repair as a result of such maintenance and overhauls which affect or may affect certification is to be noted in the unit's log and submitted to the Surveyors, as required by 1/5.7.1(a).

5.7.1(c) Representation. Nothing contained in this Section or in a rule or regulation of any government or other administration, or the issuance of any report or certificate pursuant to this Section or such a rule or regulation is to be deemed to enlarge upon the representations expressed in 1/1.1 through 1/1.7 hereof, and the issuance and use of any such reports or certificates are to be governed in all respects by 1/1.1 through 1/1.7 hereof.

5.7.2 Notification and Availability for Survey

The Surveyors are to have access to certified FRP piping installations at all reasonable times. For the purpose of Surveyor monitoring, monitoring Surveyors are to also have access to certified units at all reasonable times. Such access may include attendance at the same time as the assigned Surveyor or during a subsequent visit without the assigned Surveyor. The Owners or their representatives are to notify the Surveyors for inspection on all occasions when parts of FRP piping installations not ordinarily accessible are to be examined.

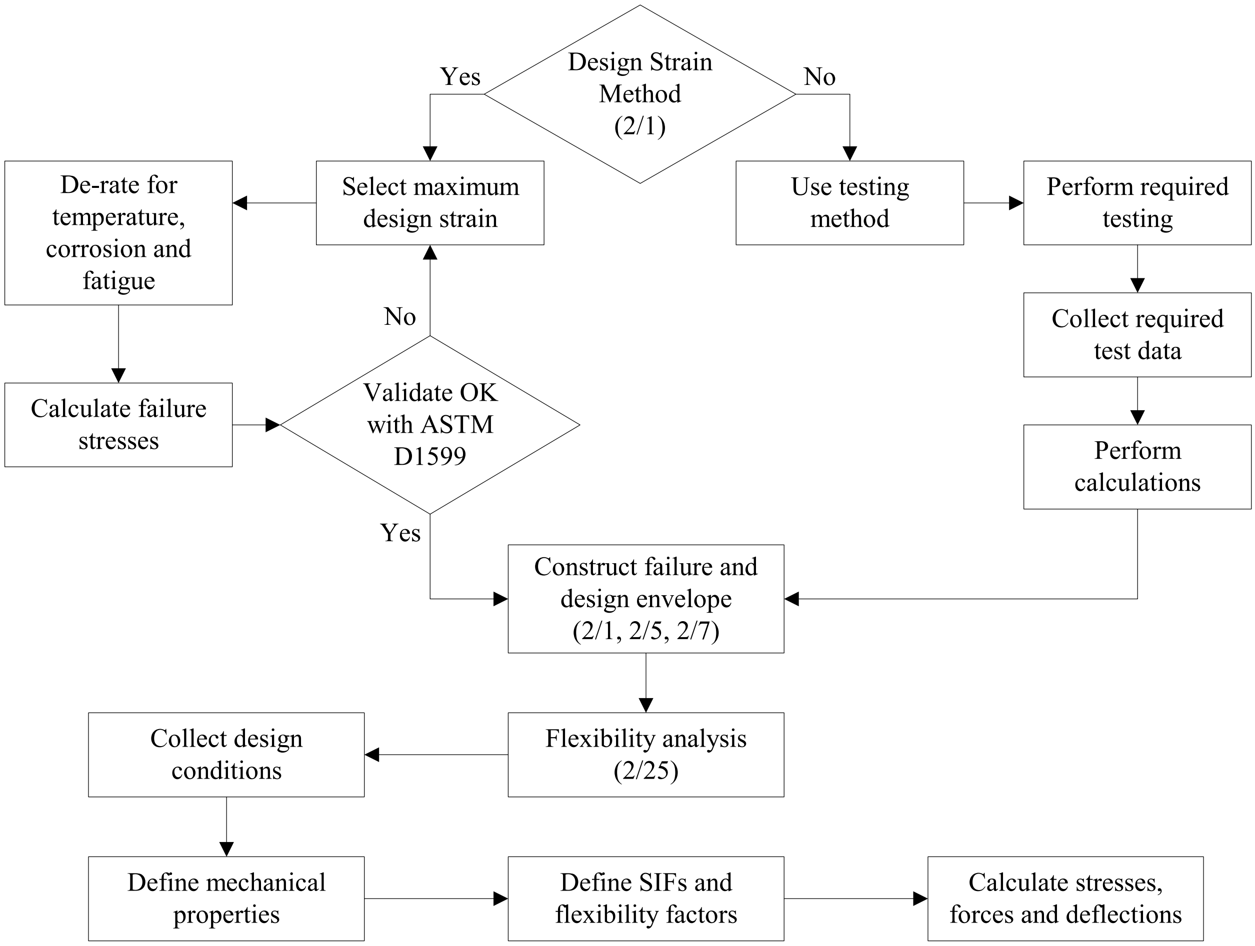
The Surveyors are to undertake all surveys on certified systems upon request, with adequate notification, of the Owners or their representatives and are to report thereon to the Committee. Should the Surveyors find occasion during any survey to recommend repairs or further examination, notification is to be given immediately to the Owners or their representatives in order that appropriate action may be taken. The Surveyors are to avail themselves of every convenient opportunity for carrying out periodical surveys in conjunction with surveys of damages and repairs in order to avoid duplication of work.

SECTION 2 Design

1 Internal Pressure

A pipe is to be designed for an internal pressure not less than the design pressure of the system in which it will be used. The maximum sustained internal pressure, P_{int}, for a pipe is to be verified by testing methods or be determined by a combination of testing and calculations methods, which are to be submitted to ABS for approval. The design flowchart in Section 2, Figure 1 may be used in the mechanical design of FRP pipes.

FIGURE 1
Flowchart of FRP Pipe Mechanical Design



1.1 Using Testing Methods

A recognized standard, such as ASTM D2992 Procedure B, is to be used as the testing method in order to determine the maximum sustained long-term hydrostatic pressure of FRP pipes. Testing temperature is to be 65°C or higher. The maximum sustained internal pressure is to be obtained by the following equation:

$$P_{int} = 0.667 f_3 P_q$$

$$P_{int} = 0.667 f_3 f_1 P_{LTHP}$$

where

P_{int}	=	maximum sustained internal pressure, MPa
P_q	=	qualified pressure, MPa
	=	$f_1 P_{LTHP}$, as specified in ASTM D2992
P_{LTHP}	=	long-term hydrostatic pressure, MPa
f_1	=	factor to represent the 97.5% Lower Confidence Limit (LCL) of P_{LTHP} based on a design life of 20 years.
f_3	=	de-rating factor to account for non-isotropic properties of FRP, always less than or equal to 1.0; default value of 0.7 for 55-degree filament wound pipes and 1.0 for isotropic materials. See also 2/25.3 for further information.

Alternatively, short term burst testing per ASTM D1599 is another acceptable testing method. A minimum of two samples is to be burst tested and the lower value is to be defined as the burst pressure, P_{burst}. The maximum sustained internal pressure, P_{int}, can be defined as:

$$P_{int} = 0.25 P_{burst}$$

where

P_{int}	=	maximum sustained internal pressure, MPa
P_{burst}	=	burst pressure, MPa

From the burst testing data, the short-term hoop stress can be determined by:

$$\sigma_{sh} = \frac{P_{burst} D}{2t_r}$$

where

σ_{sh}	=	short-term hoop stress due to internal pressure, MPa
P_{burst}	=	burst pressure, MPa
D	=	mean structural diameter, mm
	=	$D_i + 2t - t_r$
D_i	=	inside diameter, mm
t	=	total wall thickness, mm
t_r	=	average reinforced thickness of the wall (i.e., excluding the thickness of linear and added thickness for fire protection), mm

1.3 Using Design Strain Method

The following design strain based method is to be used to calculate P_{int}:

$$\sigma_h = \frac{\varepsilon_f E_h}{\eta}$$

$$P_{int} = \frac{2 f_3 t_r \sigma_h}{D}$$

where

σ_h	=	allowable hoop stress due to internal pressure, MPa
ε_f	=	long-term failure strain, default value of 0.00375
η	=	safety factor, default value of 1.5, as specified in 2/25.7
E_h	=	hoop tensile modulus, as specified in 2/25.3, MPa
P_{int}	=	maximum sustained internal pressure, MPa
f_3	=	de-rating factor, as specified in 2/1.1

D and t_r are specified in 2/1.1.

3 External Pressure

External pressure is to be considered for any installation that may be subject to vacuum conditions inside the pipe or a head of liquid on the outside of the pipe, such as green water effects. A pipe is to be designed for an external pressure not less than the sum of the pressure imposed by the maximum potential head of liquid outside the pipe plus full vacuum, 1 bar (1 kgf/cm^2, 14.5 psi), inside the pipe. The maximum external pressure for a pipe is to be determined by dividing the collapse test pressure by a safety factor of 3.

The collapse test pressure is to be verified by testing methods or be determined by a combination of testing and calculation methods, which are to be submitted to ABS for approval. A recognized standard, such as ASTM D2925, is to be used as the testing method and the following equation is to be used to calculate the allowable external pressure:

$$P_c = \frac{2E_{fh}}{\eta}\left(\frac{t_r}{D}\right)^3$$

where

P_c	=	allowable external pressure, MPa
E_{fh}	=	hoop flexural modulus, as specified in 2/25.3, MPa
η	=	safety factor, default value of 3.0

D and t_r are specified in 2/1.1.

This equation assumes the pipe is adequately supported, but it does not take into account any additional stiffness from stiffener rings which can be employed. If stiffener rings are employed to increase the allowable external pressure, an alternate equation acceptable to ABS may be used.

5 Axial Strength

The sum of the axial stresses due to pressure, weight, expansion and other dynamic and sustained loads is not to exceed the allowable stress in the axial direction. The allowable axial strength is to be determined by a combination of testing and calculation methods, which are to be submitted to ABS for approval.

Since many FRP components are non-isotropic materials, the allowable axial stress may differ from the allowable hoop stress. For 55-degree filament wound pipe, the allowable axial stress will actually vary depending upon the magnitude of the hoop stress. Therefore, it is normally necessary to perform two tests to accurately determine the allowable axial stresses of FRP components:

i) ASTM D2105 test for a pure short-term axial stress (hoop-to-axial stress ratio is 0 to 1)

ii) ASTM D1599 or ASTM D2992 pressure testing for the case when hoop-to-axial stress ratio (short term and long term, respectively) is 2 to 1.

Strain estimates are also a valid tool for determining the pure axial strength, where hoop-to-axial stress ratio is 0 to 1, of a non-isotropic FRP component. The following design strain calculations are to be used to determine the short-term axial strength:

$$\sigma_{sa} = K_a \varepsilon_{f\text{-}s} E_t$$

where

σ_{sa} = design strain based axial strength (short term), MPa

K_a = factor to account for degree of anisotropy, typically 0.5 for 55degree filament wound laminates and 1.0 for isotropic laminates ($E_h = E_t$) as specified in 2/25.3

$\varepsilon_{f\text{-}s}$ = short-term failure strain, default value of 0.012

E_h = hoop tensile modulus, as specified in 2/25.3, MPa

E_t = axial tensile modulus, as specified in 2/25.3, MPa

From these tests and calculations, the allowable axial stresses can be determined from the following equations.

For the allowable pure axial stress where hoop-to-axial stress ratio is 0 to 1:

$$\sigma_a = \frac{\sigma_{sa}\sigma_{qs}}{\eta\sigma_{sh}}$$

$$= \frac{0.5r\sigma_{qs}}{\eta}$$

where

σ_a = allowable axial stress when hoop-to-axial stress ratio is 0 to 1, MPa

σ_{sa} = ASTM D2105 axial strength or design strain based axial strength (short-term) as obtained above for pure axial strength, MPa

σ_{sh} = short-term hoop strength due to internal pressure obtained from ASTM 1559 burst test, as specified in Subsection 2/1, MPa

η = safety factor, default value of 1.5 as specified in 2/25.7

r = $2\sigma_{sa}/\sigma_{sh}$, bi-axial stress ratio (see also Subsection 2/11)

σ_{qs} = $\dfrac{P_q D}{2t_r}$, MPa

P_q = qualified pressure, MPa

= $f_1 P_{LTHP}$, as specified in ASTM D2992

P_{LTHP}, f_1, D and t_r are specified in 2/1.1.

For the allowable axial stress where hoop-to-axial stress ratio is 2 to 1:

$\sigma_{a1h2} = \sigma_{qs}$ for $r \leq 1.0$

$\sigma_{a1h2} = 0.5r\sigma_{qs}$ for $r > 1.0$

where

σ_{a1h2} = allowable axial stress when hoop-to-axial stress ratio is 2 to 1, MPa

σ_{qs} and r are as defined above.

7 Bending Strength

The sum of the bending (also called axial flexural) stresses due to pressure, weight, expansion and other dynamic and sustained loads is not to exceed the allowable bending stress. The allowable bending strength is to be determined by a combination of testing and calculation methods, which are to be submitted to ABS for approval.

Bending strength is a more complicated mechanical property since extensive long-term testing data is limited. A recognized standard, such as ASTM D2925 or ASTM D790 modified for pipes, is to be used as the testing method.

Design strain based method is also a valid tool for determining the short-term bending strength of a non-isotropic FRP component, which can be obtained by:

$$\sigma_{sb} = \varepsilon_{f\text{-}s} E_b$$

where

σ_{sb} = design strain based axial strength (short-term), MPa

$\varepsilon_{f\text{-}s}$ = short-term failure strain, default value of 0.012

E_b = bending (axial flexural) modulus, as specified in 2/25.3), MPa

From these tests and calculations, the allowable bending stress can be determined by:

$$\sigma_b = \frac{\sigma_{sb}\sigma_{qs}}{\eta\sigma_{sh}}$$

$$= \frac{0.5r_b\sigma_{qs}}{\eta}$$

where

σ_b = allowable bending stress, MPa

σ_{sb} = ASTM D2925 or D790 bending strength or design strain based bending strength (short-term) as obtained above, MPa

σ_{sh} = short-term hoop strength due to internal pressure, as specified in Subsection 2/1, MPa

r_b = $2\sigma_{sb}/\sigma_{sh}$

η = safety factor, default value of 1.5 as specified in 2/25.7

σ_{qs} is as defined in Subsection 2/7.

9 Axial Compressive Strength (Buckling)

Axial compressive strength is to be considered in systems where these types of stresses can be generated. Examples include axially-restrained straight runs of pipe with thermal expansion and vertical runs of pipe supported from underneath.

The allowable axial compressive stress is to be determined by the following method:

$$\sigma_{ac} = k \frac{\pi^2 D^2 E_a}{8\eta L^2}$$

where

σ_{ac} = allowable axial compressive stress, MPa

k = 10^{-6}

D = mean structural diameter, as specified in 2/1.1, mm

E_a = axial tensile modulus, as specified in 2/25.3, MPa

L = unsupported length of pipe (center to center distance between supports), m

η = safety factor, default value of 3.0; combined loading conditions may require a higher safety factor

In the above equation, the moment of inertia is estimated as $\pi D^3 t_r/8$ and the reinforced area as $\pi D t_r$, where D and t_r are defined in 2/1.1.

11 Biaxial Stress Ratio of Pipes, Fittings and Joints

The biaxial stress ratio is used to define the mechanical properties of non-isotropic materials, such as FRP pipes, fittings and joints. The failure and design envelopes can be established based on the given biaxial stress ratio of the individual FRP piping components. The biaxial stress ratio of pipes, fittings or joints is to be selected from the default values given in Section 2, Table 1 if no reliable data are available, or is to be determined according to the following equation:

$$r = \frac{2\sigma_{sa}}{\sigma_{sh}}$$

where

r = biaxial stress ratio

σ_{sa} = ASTM D2105 axial strength or design strain based axial strength (short-term) as obtained above in Subsection 2/5 for pure axial strength of FRP pipes, MPa

σ_{sh} = short-term hoop strength of FRP pipes due to internal pressure, as specified in Subsection 2/1, MPa

TABLE 1
Biaxial Stress Ratios

Component	*Default Biaxial Stress Ratio, r*
55-degree Filament Wound Pipe	0.5
Filament Wound Fittings, primarily hoop wound	0.45
Laminated Fittings with bidirectional reinforcement	1.9
Adhesive Bonded Joints	1.0
Laminated Joints with bidirectional reinforcement	2.0

For fittings and joints, the pressure induced responses are much more complex than those in plain pipes. Appropriate experimental or analytical methods are to be adopted to determine the short term axial and hoop strengths.

Note that the biaxial stress ratio defined in this Guide is not the same as, nor has any relationship to, the coefficient of correlation in ASTM D2992.

13 Temperature

The maximum allowable working temperature of a pipe is to be in accordance with the Manufacturer's recommendations, but in every instance, is to be at least 20°C (36°F) lower than the minimum heat distortion temperature (HDT) of the pipe material, determined according to ISO 75 method A or equivalent. The minimum HDT is not to be less than 80°C (176°F) unless calculations and testing are shown to validate a product with an HDT below this value.

At elevated temperatures, degradation of material properties is to be considered. In general, FRP materials have stable mechanical properties up to 65°C (150°F). Above this temperature, FRP materials may show some degradation. At the HDT, the material properties may be 50% or less than the ambient temperature properties.

Where low temperature services are considered, special attention is to be given with respect to material properties. Some testing has shown FRP to have stable mechanical properties to as low as -40°C (-40°F).

15 Material Compatibility

The piping material is to be compatible with the fluids being conveyed or in which it is immersed. Both the internal and external surfaces of the piping components are to include a corrosion barrier suitable for the application. Typically, this corrosion barrier is at least 0.5 mm thick on the interior and at least 0.25 mm thick on the exterior. However, interior corrosion barriers of 2.5 mm thickness or more may be needed for certain corrosive applications. The Manufacturer is to submit data to ABS to support their corrosion barrier thickness.

If a sodium hypochlorite solution is used in the seawater system to combat the growth of marine organisms and algae that could foul filters and pipelines, then data is to be submitted to ABS to support the use of FRP in this service. Sodium hypochlorite is a very aggressive chemical. However, at the concentrations (<100 ppm) and temperatures (<52°C or 125°F) typically used for control of marine growth, many FRP products are suitable for exposure to this solution. Storage tanks may require special manufacturing techniques [such as a 2.8 mm (0.110 in.), liner and a special liner cure system and reinforcement] since the concentration of sodium hypochlorite can be much higher. Other precautions for storage tanks, such as a pigmented UV-inhibited exterior gel coat to prevent UV exposure, may also need to be considered.

17 Environmental Conditions

The piping material is to be suitable for the environmental conditions of the application, which may include the following: exposure to UV rays, exposure to salt air and exposure to oil and grease.

All piping components are to have an external corrosion barrier suitable for the application. Typically, an external corrosion barrier of 0.25 mm that contains UV absorbers and veil reinforcement is suitable for protecting the structural cage from UV rays and exposure to salt air, oil and grease. A synthetic veil material may provide better protection than a C-glass or E-glass veil. This external corrosion barrier thickness is not in addition to the external corrosion barrier thickness specified in Subsection 2/15. The Manufacturer is to submit data to ABS to support their corrosion barrier thickness.

19 Impact Resistance

FRP pipes and joints are to meet a minimum resistance to impact in accordance with a recognized national or international standard such as ISO14692-2, Clause 6.4.3 or an equivalent standard. ASTM D256 may also be considered. However, this standard only reports an impact resistance. The average minimum required impact resistance is to be 961 J/m of width (18 ft-lbf/in of width) per Test Method E or a value acceptable to the Surveyor.

The minimum structural wall thickness for any pipe is to be 3 mm. 5 mm is strongly recommended for more robustness. Thickness of 6 mm or more may be required for certain fire protection applications.

21 Hydraulic Design

The inside pipe diameter is to be selected to attain the necessary fluid flow for the application. Velocities are to be limited to values that prevent the unacceptable pressure loss, cavitation, erosion, noise and abrasion.

For typical FRP applications, the average liquid fluid velocity is between 1 and 5 meters/second with intermittent excursions up to 10 m/s. For gas flows, the average gas velocity is between 1 and 10 m/s with intermittent excursions up to 20 m/s.

For information on pressure surges and water hammer, refer to Subsection 2/25.

23 Ship Motions

Ship motions and their effect on deflections and stresses on the FRP piping installation are to be considered. Ship motions from 1) lifting and transportation of ship hull or topside module, 2) daily wave action, and 3) storm wave action are to be considered. Inertial loads from ship motions are also to be considered. Flexure of the hull due to racking is also to be considered.

25 Stress Analysis

A stress analysis is to be performed on the FRP piping installation. The degree of detail of this stress analysis is to be determined based on the complexity of the piping installation, the design conditions and the level of criticality of the system. The flowchart in Section 2, Figure 2 summarizes the stress analysis procedures for FRP pipes.

25.1 Design Conditions

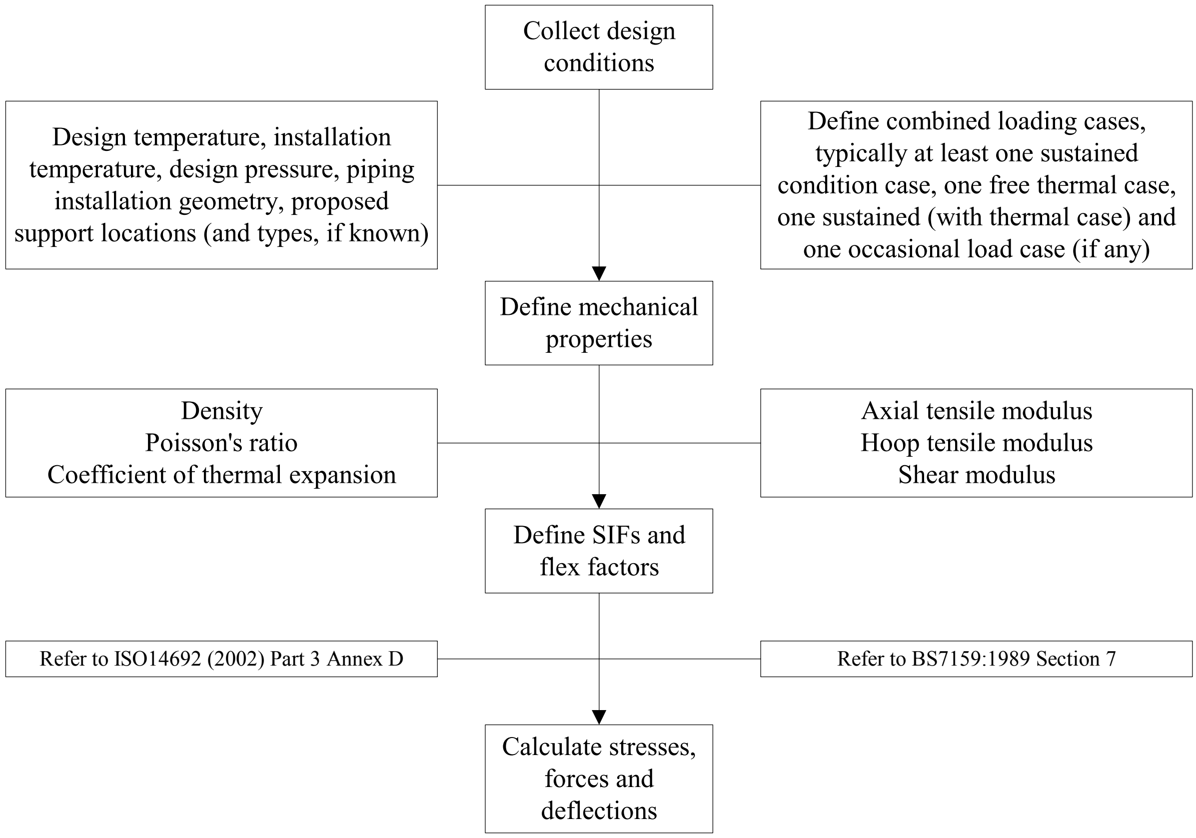
For simple stress analysis calculations, the following design conditions are required inputs:

- Pipe sizes and wall thickness
- Design and installation temperature
- Design pressure
- Support spacing (center to center distance between supports)

For a more detailed flexibility analysis, the following design conditions are required inputs:

- Detailed piping installation geometry, including valves and other in-line components
- Proposed support locations and types
- Combined loading cases, normally consisting of at least one sustained condition case, one free thermal run, one sustained thermal case and any occasional load cases

FIGURE 2
Stress Analysis Flowchart



25.3 Material Properties

The following mechanical properties are required inputs:

ρ = density

ν = Poisson's ratio (hoop-to-axial strain resulting from an axial stress)

E_a, E_t = axial tensile modulus (Young's modulus in the axial direction)

E_h = hoop tensile modulus (Young's modulus in the hoop direction)

G = shear modulus

C_t = thermal expansion coefficient (axial direction)

Other properties which may be required are:

E_b = bending modulus (axial flexural modulus)

E_{fh} = hoop flexural modulus

Manufacturers generally optimize the performance of FRP pipes for internal pressure where the ratio of loading is 2:1 (twice as much hoop loading as axial loading). A filament winding angle of 55 degrees is typically optimal for this condition. This is one of the reasons why FRP materials are non-isotropic. It is therefore important for the designer to specify at least three modulus values (axial, hoop, shear), one Poisson's ratio (axial-to-hoop strain resulting from a hoop stress or hoop-to-axial strain resulting from an axial stress) and one thermal expansion coefficient (axial direction). There is also a thermal expansion coefficient in the hoop direction, but this is normally not required for FRP piping design.

Typical values for a 55-degree filament wound pipe are as follows:

ν = 0.30 to 0.40 (hoop-to-axial strain resulting from an axial stress)

E_a, E_t = 9 to 12 GPa

E_h = 15 to 22 GPa

G = 7 to 11 GPa

C_t = 0.000018 m/m/°C (axial direction)

E_b = 9 to 12 GPa

E_{fh} = 15 to 22 GPa

Because of the non-isotropic nature of FRP materials, the equation for determining the maximum sustained internal pressure includes a de-rating factor. Further information on this de-rating factor can be obtained from ISO14692-3, Clause 7.2.

Another factor is included in the equation for calculating the short-term axial strength. A single short-term failure strain is recommended in this document. However, this one value may not be viable for both short-term hoop and axial loadings. While a value of 0.012 may be suitable for hoop stresses, a 55-degree filament wound pipe may have only 0.006 for axial stresses. The K_a factor is meant to account for this.

25.5 SIFs and Flexibility Factors

Stress Intensification Factors (SIFs) and Flexibility Factors are required for a detailed flexibility analysis of the piping installation. The designer is to reference BS7159:1989 Section 7 or ISO14692-3, Annex D.

25.7 Allowable Stresses and Deflections

Since FRP is a non-isotropic material, there is often more than one allowable stress. As a minimum, there are three allowable stresses which are to be considered: 1) allowable axial stress, 2) allowable hoop stress, and 3) allowable bending stress.

Since FRP is a much lower modulus material than steel, it is often necessary to design support spacing not only on stress, but also deflection. For deflection, the allowable vertical deflection between supports is to be 12.5 mm (0.50 in.) or 0.5% of the span, whichever is less.

25.7.1 Sustained Loads

When calculating stresses due to sustained loads, the default safety factor of 1.5 is to be used for internal pressure (Subsection 2/3), axial stresses (Subsection 2/5), and bending stresses (Subsection 2/7). Sustained loads are to include: internal pressure, external pressure, vacuum, piping weight, insulation/fire protection weight, fluid weight, inertia loads due to motion during operation (e.g., daily wave action), sustained environmental loads (such as ice and snow) and other sustained loads.

25.7.2 Thermal Loads

Because of the self-limiting nature of thermal expansion loads, when calculating stresses due to thermal conditions, the default safety factor is to be 1.2 for internal pressure, axial stresses and bending stresses (Subsections, 2/3, 2/5 and 2/7, respectively).

25.7.3 Occasional Loads

When calculating stresses due to occasional loads, the default safety factor is to be 1.12 for internal pressure, axial stresses and bending stresses (Subsections, 2/3, 2/5 and 2/7, respectively). Occasional loads are to include: internal pressure from hydrotesting, pressure surges from water hammer, pressure surges from safety valve releases, transient equipment vibrations, impact, inertia loads from motion during transportation, occasional environmental loads (such as wind from storms), overpressures from blasts and other occasional loads. Some occasional loads may not need to be considered as acting concurrently.

25.7.4 Reduction of Allowable Stresses

Certain design conditions may necessitate a reduction in the allowable stress values. These may include severe corrosive conditions, elevated temperatures and cyclic loading conditions.

For a design cycle life of 7,000 cycles or less, the design may be considered as static and a reduction of allowable stresses due to fatigue concerns is not necessary.

25.9 Stress Analysis Calculations

The following stresses are to be considered in a stress analysis:

- Hoop stress due to internal pressure
- Axial stress due to internal pressure
- Axial compressive stress due to thermal expansion
- Bending stress due to dead weight
- Bending stress due to thermal and pressure expansion
- Hoop flexural stress due to vacuum
- Any other stresses due to sustained, thermal or occasional loads.

Deflection due to dead weight is also to be calculated.

25.9.1 Hoop Stress due to Internal Pressure

$$\sigma_{hp} = \frac{PD}{2t_r}$$

where

σ_{hp}	=	hoop stress due to internal pressure, MPa
P	=	design pressure, MPa

D and t_r are specified in 2/1.1.

25.9.2 Axial Stress due to Internal Pressure

$$\sigma_{ap} = \frac{PD}{4t_r}$$

where

σ_{ap}	=	axial stress due to internal pressure, MPa
P	=	design pressure, MPa

D and t_r are specified in 2/1.1.

25.9.3 Axial Compressive Stress Due to Thermal Expansion (with Constrained Ends)

$$\sigma_{ac} = C_t \Delta T E_t$$

where

σ_{ac}	=	axial compressive stress due to thermal expansion, MPa
C_t	=	axial thermal expansion coefficient, as specified in 2/25.3, mm/mm/°C
ΔT	=	design temperature change, °C
E_t	=	axial tensile modulus, as specified in 2/25.3, MPa

25.9.4 Bending Stress due to Dead Weight (2-span Beam Equation)

$$\sigma_{ab} = k\frac{Mc}{I_r}$$

where

σ_{ab}	=	bending stress due to dead weight, MPa
k	=	1000
M	=	$9.8w_oL^2/8$, N-m
w_o	=	pipe (with internal fluid) mass per unit length, kg/m
L	=	support spacing, m
c	=	mean structural radius, mm
	=	$D/2$
I_r	=	reinforced moment of inertia, mm^4
	=	$\pi[(D_i+2t_r)^4 - D_i^4]/64$

D, t, D_i and t_r are specified in 2/1.1.

25.9.5 Thermal Expansion

$$\ell_{TE} = \Delta T\, kC_t\Delta T$$

where

ℓ_{TE}	=	thermal expansion, mm/m
k	=	1000
C_t	=	thermal expansion coefficient, as specified in 2/25.3, mm/mm/°C
ΔT	=	design temperature change, °C

25.9.6 Pressure Expansion

$$\ell_{PE} = k\frac{Pc}{t_r}\left(\frac{1}{2E_t} - \frac{\nu}{E_h}\right)$$

where

ℓ_{PE}	=	pressure expansion, mm/m
k	=	1000
P	=	design pressure, MPa
c	=	mean structural radius, as specified in 2/25.9.4, mm
t_r	=	average reinforced wall thickness, as specified in 2/1.1, mm
E_t	=	axial tensile modulus, as specified in 2/25.3, MPa
ν	=	Poisson's ratio
E_h	=	hoop tensile modulus, as specified in see 2/25.3, MPa

25.9.7 Bending Stress Due to Expansion

$$\sigma_{ab} = \frac{kMc}{I_r}$$

where

σ_{ab} = bending stress due to expansion, MPa

k = 1000

M = bending moment created from expansion, N-m

c = mean structural radius, as specified in 2/25.9.4, mm

I_r = reinforced moment of inertia, as specified in 2/25.9.4, mm^4

25.9.8 Hoop Flexural Stress Due to Vacuum and/or External Pressure

$$\sigma_{hfc} = 2E_{fh}\left(\frac{t_r}{D}\right)^3$$

where

σ_{hfc} = hoop flexural stress due to vacuum and/or external pressure, MPa

E_{fh} = hoop flexural modulus, as specified in 2/25.3, MPa

D and t_r are specified in 2/1.1.

25.9.9 Wind Loads

Refer to ASCE7-88 or other suitable standards for calculating forces and stresses due to wind loads.

25.9.10 Deflection Due to Dead Weight (2-span beam equation)

$$\Delta s = \frac{5kw_o L_s^4}{925 E_b I_r}$$

where

Δs = deflection due to dead weight, mm

k = 9.8×10^9

w_o = pipe (with internal fluid) mass per unit length, kg/m

L_s = support spacing, m

E_b = bending modulus, as specified in 2/25.3, MPa

I_r = reinforced moment of inertia, as specified in 2/25.9.4, mm^4

27 Fire Endurance

Fire endurance requirements for pipes based on system and location are specified in Section 2, Table 3. Pipes and their associated fittings whose functions or integrity are essential to the safety of the installation are to meet the fire endurance requirements described below. The fire endurance rating code L1, L2, L3, or L3-WD is to be assigned to FRP piping components upon the satisfaction of the fire endurance testing described below.

27.1 Level 1

Level 1 will ensure the integrity of the system during a full scale hydrocarbon fire, and is particularly applicable to systems where loss of integrity may cause outflow of flammable liquids and worsen the fire situation. Piping having passed the fire endurance test specified in Section 6 for a minimum duration of one hour without loss of integrity in the dry condition is considered to meet Level 1 fire endurance standard (L1).

27.3 Level 2

Level 2 intends to ensure the availability of systems essential to the safe operation of the installation after a fire of short duration, allowing the system to be restored after the fire has been extinguished. Piping having passed the fire endurance test specified in Section 6 for a minimum duration of 30 minutes without loss of integrity in the dry condition is considered to meet Level 2 fire endurance standard (L2).

27.5 Level 3

Level 3 is considered to provide the fire endurance necessary for a water-filled piping installation to survive a local fire of short duration. The system's functions are capable of being restored after the fire has been extinguished. Piping having passed the fire endurance test specified in Section 7 for a minimum duration of 30 minutes without loss of integrity in the wet condition is considered to meet Level 3 fire endurance standard (L3).

27.7 Level 3 Modified Test

Level 3 modified test for deluge systems is considered to provide the fire endurance necessary for a piping installation to survive a local fire of short duration, with a simulated dry condition and subsequent flowing water condition. The system's functions are capable of being restored after the fire has been extinguished. Piping having passed the fire endurance test specified in Section 8 for a minimum duration of 5 minutes in dry condition and 25 minutes in wet condition without loss of integrity is considered to meet the Wet/Dry fire endurance standard (L3-WD).

27.9 Fire Endurance Coating

When a fire-protective coating of pipes and fittings is necessary for achieving the fire endurance standards required, the following requirements apply:

i) Pipes are generally to be delivered from the Manufacturer with the protective coating applied, with onsite application limited to that necessary for installation purposes (i.e., joints). See Subsection 3/13 regarding the application of the fire protection coating on joints.

ii) The fire protection properties of the coating are not to be diminished when exposed to salt water, oil or bilge slops. It is to be demonstrated that the coating is resistant to products likely to come in contact with the piping.

iii) In considering fire protection coatings, such characteristics as thermal expansion, resistance against vibrations and elasticity are to be taken into account.

iv) The fire protection coatings are to have sufficient resistance to impact to retain their integrity.

v) For electrically conductive systems, refer to Subsection 2/31.

29 Flame Spread

All pipes except for those fitted on open decks and within tanks, cofferdams, void spaces, pipe tunnels and ducts are to have low flame spread characteristics. The test procedures in IMO Resolution A.653 (16), modified for pipes as indicated in Section 9, are to be used for determining the flame spread characteristics. Piping materials giving average values for all of the surface flammability criteria not exceeding the values listed in IMO Resolution A.653 (16) (surface flammability criteria of bulkhead, wall and ceiling linings) are considered to meet the requirements for low flame spread.

Alternatively, flame spread testing in accordance with ASTM D635 may be used in lieu of the IMO flame spread test, provided such test is acceptable to the Administration. Under the ASTM D635 test method, the FRP pipe may be considered self-extinguishing if none of the ten (or no more than one of the twenty) specimens have burned to the 100-mm (3.9 in.) mark.

31 Electrical Conductivity

31.1 Rating

Electric conductivity or electrostatic dissipative properties of FRP piping is to be rated according to the requirements of ISO 14692-2, Clause 6.6 and Annex G.

Where electrically conductive pipe is required, the resistance per unit length of the FRP pipes and fittings is not to exceed 10^5 Ohm/m (3.28×10^4 Ohm/ft), and the requirements associated with rating (classification) code C1a, C2a, or C3 are to be satisfied.

31.3 Non-homogeneous Conductivity

Homogenously conductive systems, such as conductive coatings that cover the entire exterior or carbon-loaded resins that allow the resin to conduct, are preferred over non-homogenous systems.

Pipes and fittings that use discrete conductive filaments to achieve electrical conductivity are to be protected against the possibility of spark damage to the pipe wall. There are to be no electrically isolated discrete conductive filaments in the piping installation.

31.5 Design Requirements

31.5.1 Conductivity of Internal Fluids

Piping conveying fluids with conductivity less than 1000 pS/m (pico-siemens per meter) is to be internally electrically conductive and is to provide an adequate electrical path to ground. Natural gasoline, motor and aviation gasoline, diesels, kerosene, heating oils, lubricating oils and jet fuels typically have conductivities lower than 1000 pS/m (usually they are less than 50 pS/m). Seawater and crude oil typically have conductivities higher than 1000 pS/m (deionized water, for example, is about 10^6 pS/m).

31.5.2 Hazardous Areas

If the FRP pipes pass through hazardous areas defined in 2-1/49 of the ABS *Facilities Guide*, then the pipes are either 1) to be externally electrically conductive and are to provide an adequate electrical path to ground or 2) are to be evaluated for risk assessment to determine the need for electrical conductivity.

If electrical conductivity is required and if any of the pipes or components are insulated or have fire protection on the exterior, then the insulation/fire protection is also to be externally electrically conductive and is to have an adequate electrical path to ground. In such a situation, it may be acceptable to use non-conductive FRP pipes, provided the insulation/fire protection is electrically conductive and has an adequate electrical path to ground. Data on the insulation/fire protection is to be submitted to ABS for review and approval.

Section 2, Table 2 is to be used as a guideline for a risk assessment method to determine the need for electrical conductivity. Guidelines for both internal and external charge-generating mechanisms are included. Data from the risk assessment is to be submitted to ABS for review and approval.

Weak external charge-generating mechanisms include, but are not limited to, tribocharging. Moderate external charge-generating mechanisms include, but are not limited to, tank washing operations. Strong external charge-generating mechanisms include, but are not limited to, cargo tank cleaning/purging/loading operations and an efflux of a two-phase fluid past the FRP pipe. An example may include a gas with condensed droplets leaking from a nearby steam or hydrocarbon pipe.

Changing atmospheric conditions, particularly near strong thunderstorms, have the possibility of being moderate to strong external charge-generating mechanisms. However, in the case of lightning, it is more likely that the lightning strike itself provides a more significant ignition source than any discharge that could occur from the FRP pipes, whether electrically conductive or not.

Tank washing operations that use crude oil washing (COW) techniques (with dry crude oil) or small water washing machines can help minimize their charge-generating potential.

Isolated metal objects of significant size that are in close proximity to earthed objects (both fixed and mobile, including personnel) are to be given particular attention since these can contribute to the potential creation of an incentive discharge.

33 Marking

FRP pipes and other components are to be permanently marked with identification in accordance with a recognized standard. Identification is at least to include:

i) Manufacturer's information

ii) Standard to which the pipe or fitting is manufactured

iii) Material with which the pipe or fitting is constructed

vi) Nominal diameter

v) Pressure rating (maximum sustained internal pressure)

vi) Fire endurance rating

vii) Electric conductivity rating

TABLE 2
Electrical Conductivity Risk Assessment Guidelines

	Service Conditions	*Guidelines*
Internal charge-generating mechanisms	Piping that contains fluids with conductivities greater than 1000 pS/m	No internal conductivity requirement.
	Piping that may contain fluids with conductivities less than 1000 pS/m	Piping is to have a resistance from inside to outside the pipes of 10^5 ohms per meter or less. Conductive piping and all isolated metal objects of significant size are to be earthed with a maximum resistance to earth of 10^6 ohms.
External charge-generating mechanisms	Piping not located in hazardous areas.	No conductivity requirement.
	Piping located in hazardous areas that may be exposed to weak external charge-generating mechanisms during normal operations	No conductivity requirement except all isolated metal objects of significant size are to be earthed with a maximum resistance to earth of 10^8 ohms.
	Piping located in hazardous areas that may be exposed to moderate external charge-generating mechanisms	Piping is to have a resistance of 10^5 ohms per meter or less. Conductive piping and all isolated metal objects of significant size are to be earthed with a maximum resistance to earth of 10^8 ohms.
	Piping located in hazardous areas that may be exposed to strong external charge-generating mechanisms	Piping is to have a resistance of 10^5 ohms per meter or less. Piping and all isolated metal objects of significant size are to be earthed with a maximum resistance to earth of 10^6 ohms.

TABLE 3
Fire Endurance Requirements Matrix

PIPING INSTALLATIONS		LOCATION										
		A	B	C	D	E	F	G	H	I	J	K
HYDROCARBON &CARGO (Flammable cargoes with flash point ≤ 60°C (140°F))												
1	Cargo lines	NA	NA	L1			0	NA	0	0	NA	L1[2]
2	Crude oil washing lines	NA	NA	L1			0	NA	0	0	NA	L1[2]
3	Vent lines	NA	NA	NA			0	NA	0	0	NA	X
3a	Process lines	NA	NA	NA			0	NA	0	0	NA	L1[2]
3b	Produced water lines	NA	NA	NA			0	NA	0	0	NA	L3[10]
INERT GAS												
4	Water seal effluent line	NA	NA	0[1]			0[1]	0[1]	0[1]	0[1]	NA	0
5	Scrubber effluent line	0[1]	0[1]	NA			NA	NA	0[1]	0[1]	NA	0
6	Main line	0	0	L1			NA	NA	NA	0	NA	L1[6]
7	Distribution lines	NA	NA	L1			0	NA	NA	0	NA	L1[2]
FLAMMABLE LIQUIDS [flash point > 60°C (140°F)]												
8	Cargo lines	X	X	L1			NA[3]	0	0	0	NA	L1
9	Fuel oil	X	X	L1			NA[3]	0	0	0	L1	L1
10	Lubricating oil	X	X	L1			NA	NA	NA	0	L1	L1
11	Hydraulic oil	X	X	L1			0	0	0	0	L1	L1
SEA WATER (See Note 1)												
12	Bilge main and branches	L1[7]	L1[7]	L1			NA	0	0	0	NA	L1
13	Fire main	L1	L1	L1			NA	NA	0	0	X	L1/L3[11]
13a	Water spray (Deluge)	L1	L1	L1			NA	NA	0	0	X	L1/LWD[11]
14	Foam system	L1	L1	L1			NA	NA	NA	0	L1	L1
15	Sprinkler system	L1	L1	L3			NA	NA	0	0	L3	L3
16	Ballast	L3	L3	L3			0	0	0	0	L2	L2
17	Cooling water, essential services	L3	L3	NA			NA	NA	0	0	NA	L2
18	Tank cleaning services, fixed machines	NA	NA	L3			0	NA	0	0	NA	L3[2]
19	Nonessential systems	0	0	0			NA	0	0	0	0	0
FRESH WATER												
20	Cooling water, essential services	L3	L3	NA			NA	0	0	0	L3	L3
21	Condensate return	L3	L3	L3			NA	NA	NA	0	0	0
22	Nonessential systems	0	0	0			NA	0	0	0	0	0
SANITARY/DRAINS/SCUPPERS												
23	Deck drains (internal)	L1[4]	L1[4]	NA			NA	0	0	0	0	0
24	Sanitary drains (internal)	0	0	NA			NA	0	0	0	0	0
25	Scuppers and discharges (overboard)	0[1,8]	0[1,8]	0[1,8]			0	0	0	0	0[1,8]	0
VENTS/SOUNDING												
26	Water tanks/dry spaces	0	0	0			0	0	0	0	0	0
27	Oil tanks [flash-point > 60°C (140°F)]	X	X	X			X[3]	0	0	0	X	X
MISCELLANEOUS												
28	Control air	L1[5]	L1[5]	L1[5]			NA	0	0	0	L1[5]	L1[5]
29	Service air (non-essential)	0	0	0			NA	0	0	0	0	0
30	Brine	0	0	NA			NA	NA	NA	0	0	0
31	Auxiliary low pressure steam [Pressure ≤ bar (7 kgf/cm^2, 100 psi)]	L2	L2	0[9]			0	0	0	0	0[9]	0[9]

TABLE 3 (continued) Fire Endurance Requirements Matrix

Locations		*Abbreviations*	
A	Category A machinery spaces	L1	Fire endurance test in dry conditions, 60 minutes, in accordance with Section 6
B	Other machinery spaces	L2	Fire endurance test in dry conditions, 30 minutes, in accordance with Section 6
C	Cargo pump rooms	L3	Fire endurance test in wet conditions, 30 minutes, in accordance with Section 7
D	Not needed	LWD	Fire endurance test in dry condition, 5 minutes, and in wet condition 25 minutes, in accordance with Section 7 and Section 8
E	Not needed	0	No fire endurance test required
F	Cargo tanks	NA	Not applicable
G	Fuel oil tanks	X	Metallic materials having a melting point greater than 925°C (1700°F).
H	Ballast water tanks		
I	Cofferdams, void spaces, pipe tunnels and ducts		
J	Accommodation, service and control spaces		
K	Open decks		

Notes:

1 Where nonmetallic piping is used, remotely controlled valves are to be provided at the vessel/unit's side. These valves are to be controlled from outside the space.

2 Remote closing valves are to be provided at the cargo tanks and hydrocarbon liquid and gas retaining components as applicable.

3 When cargo tanks contain flammable liquids with a flash point greater than 60°C (140°F), "0" may replace "NA" or "X".

4 For drains serving only the space concerned, "0" may replace "L1".

5 When controlling functions are not required by statutory requirements, "0" may replace "L1".

6 For pipe between machinery space and deck water seal, "0" may replace "L1".

7 For passenger vessels, "X" is to replace "L1".

8 Scuppers serving open decks in positions 1 and 2, as defined in Regulation 13 of the International Convention on Load Lines, 1966, are to be "X" throughout unless fitted at the upper end with the means of closing capable or being operated from a position above the freeboard deck in order to prevent down-flooding.

9 For essential services, such as fuel oil tank heating and ship's whistle, "X" is to replace "0".

10 Metallic ESD valves are to be provided together with fire detection, fire fighting and shutdown system

11 Lower level of fire resistant tests (Level 3 and Level WD) may be considered for the fire water ring main and deluge systems, provided the system arrangement meet the following:

Firewater Ringmain System Arrangements:

i) The firewater system is to be permanently in a charged condition (wet main).

ii) FRP piping must be located on the exterior perimeter of the vessels/units and shielded by primary structural members from potential sources of fire that may occur on or emanate from the vessels/units.

iii) FRP piping must be located so that pooling of flammable liquids below the piping is not possible. A properly designed drainage system may be provided to mitigate the pooling of flammable liquid below the piping installation.

iv) The firewater system is to be equipped with an adequate number of isolation and cut-off valves such that, if a section of the system were to fail, it could be isolated and the remainder of the system would still be capable of supplying firewater.

TABLE 3 (continued)
Fire Endurance Requirements Matrix

Water Spray (Deluge) Systems for Process Equipment System Arrangements:

i) FRP piping is installed in open deck or semi-enclosed locations.

ii) The water spray piping installation must meet the Level 3 fire endurance requirements as specified in Section 7.

iii) In addition to meeting the Level 3 fire endurance requirements, the water spray piping installation must meet the requirements of the wet/dry fire endurance testing specified in Section 8. Other wet/dry fire endurance test methods that may be equivalent or more severe than the methods described in Section 8 will be considered on a case-by-case basis.

iv) An automatic fire detection system is to be installed in areas protected by the water spray system.

v) The water spray system is to be designed to activate automatically upon detection by the automatic fire detection system.

vi) Each section or area served by a water spray system is to be capable of being isolated by one water supply valve only. The stop valve in each section is to be readily accessible and its location clearly and permanently indicated.

vii) The design of the water spray system is to be such that upon fire detection, the time required to have water flowing through the hydraulically most remote nozzle is less than one minute. This requirement will be verified by system testing at the time of installation and at subsequent annual inspections.

viii) The water spray system piping is to be located downstream of the water supply valve.

A risk analysis, subject to the approval of the Surveyor, may also be proposed to justify the use of Level 3 for firewater ring mains and Level WD for water spray (deluge) systems.

SECTION 3 Installation

1 Supports

1.1 Spacing

Selection and spacing of pipe supports in shipboard systems are to be determined as a function of allowable stresses and maximum deflection criteria. Support spacing is not to be greater than the pipe manufacturer's recommended spacing. The selection and spacing of pipe supports are to take into account pipe dimensions, mechanical and physical properties of the pipe material, mass of pipe and contained fluid, external pressure, operating temperature, thermal expansion effects, loads due to external forces, thrust forces, water hammer and vibrations, and other applicable loads to which the system may be subjected. Combinations of these loads are to be taken into consideration for the design. Typical support spacing values for FRP pipes carrying water with specific gravity of 1.0 are listed in Section 3, Table 1.

TABLE 1
Typical Support Spacing Values (fluid SG = 1.0) (1)

Pipe Size	*Support Spacing (m)*
25	2.0 to 3.2
40	2.4 to 3.6
50	2.6 to 3.9
80	2.9 to 4.4
100	3.1 to 4.8
150	3.5 to 5.0
200	3.7 to 5.8
250	4.0 to 6.5 (2)
300	4.2 to 7.1 (2)
350	4.8 to 7.7 (2)
400	4.8 to 8.2 (2)
450	4.8 to 8.7 (2)
500	5.5 to 9.0 (2)
600	6.0 to 9.0 (2)

Notes:

1 Support spacing values are highly dependent upon the wall thickness of the pipe and its mechanical properties. Actual support spacing values may be outside the ranges in this table. SG = Specific Gravity, 1.0 for water.

2 Many designs limit support spacing to 6.0 meters or less.

1.3 Bearing

Each support is to evenly distribute the load of the pipe and its contents over the full width of the support. The minimum support width (mm) is to be greater than or equal to $(30D)^{0.5}$, where D is the mean structural diameter, in mm, as specified in Subsection 2/1. In lieu of this equation, an equation acceptable to ABS is to be used. Measures, such as padding between the FRP pipe and steel support, are to be taken to minimize wear of the pipes where they come in contact with the supports.

1.5 Heavy Components

Heavy components in the piping installation, such as valves and expansion joints, are to be adequately supported. If necessary, independent support of the heavy component is to be provided.

1.7 Working of the Hull on a Floating Installation

The supports are to allow for relative movement between the pipes and the vessel/unit's structure, properly accounting for the difference in the coefficients of thermal expansion and deformations of the vessel/unit's hull and its structure.

Most designs of FRP piping installation do not require the use of expansion joints, due to the low modulus value of FRP. One possible exception to this is for connections between modules or for connections between two independently supported structures. In these cases, the movement of the modules provides the axial force necessary to engage the expansion joint.

1.9 Thermal Expansion

When calculating the thermal expansion, the system's working temperature and the temperature at which assembling is performed are to be taken into account.

3 External Loads

When installing piping, allowance is to be made for temporary point loads, where applicable. Such allowances are to include at least the force exerted by a load (person) of 980 N (100 kgf, 220 lbf) at midspan on any pipe more than 100-mm (4 in.) nominal diameter. Pipes are to be protected from mechanical damage where necessary.

5 Pipe Connections

5.1 General Requirements

The following general principles are applicable to all pipe connections:

i) The strength of fittings and joints is not to be less than the design strength of the system.

ii) Pipes may be joined using adhesive bonded, welded (also called laminated, butt-welded, composite-welded, or secondary overlay), flanged or other types of joints.

iii) Tightening of flanged or mechanically coupled joints is to be performed in accordance with Manufacturer's instructions.

iv) Adhesives, when used for joint assembly, are to be suitable for providing a permanent seal between the pipes and fittings through the temperature and pressure range of the intended application.

v) Nondestructive evaluation (NDE) methods are to be employed on the pipe connections prior to hydrotest to ensure reliability.

These methods include:

- Visual inspection
- Degree of cure (nondestructive)
- Joint thickness measurements

More complicated methods include:

- Acoustic emissions
- Ultrasonic testing
- Radiographic testing

Not all methods may be applicable to each type of pipe connection. For example, adhesive-bonded connections do not allow for visual inspection, degree of cure, or thickness measurements since the bonded area is enclosed once the connection is complete.

5.3 Procedure and Personnel Qualifications

Joining techniques are to be in accordance with the Manufacturer's installation guidelines. Personnel performing these tasks are to be qualified to the satisfaction of the ABS, and each bonding procedure is to be qualified before shipboard piping installation commences. Requirements for joint bonding procedures are in Section 5.

7 Electrical Conductivity

Where electrically conductive pipe is required by Subsection 2/31, installation of the pipe is to be in accordance with the following:

7.1 Resistance Measurement

The resistance to earth (ground) from any point in the system is not to exceed 1 mega-ohm. The resistance is to be checked in the presence of the Surveyor.

7.3 Grounding (Earthing) Wire

Where used, grounding (earthing) wires or bonding straps are to be accessible for inspection. The Surveyor is to verify that they are in visible locations.

9 Shell Connections on Floating Installations

Where FRP pipes are permitted in systems connected to the shell of the vessel/unit, the valves and the pipe connection to the shell are to be in accordance with applicable ABS *Rules for Building and Classing Steel Vessels* (ABS *Steel Vessel Rules*) or ABS *Rules for Building and Classing Mobile Offshore Drilling Units* (ABS *MODU Rules*) requirements. See 4-6-2/9.13 or 4-2-2/7.7, respectively.

11 Bulkhead and Deck Penetrations

i) The integrity of watertight bulkheads and decks is to be maintained where FRP pipes pass through them.

ii) Where FRP pipes pass through "A" or "B" class divisions, arrangements are to be made to ensure that fire endurance is not impaired. These arrangements are to be tested in accordance with IMO Resolution. A.754(18), Recommendation on Fire Resistance Tests for "A", "B" and "F" Class Divisions, as amended.

iii) If the bulkhead or deck is also a fire division and destruction by fire of FRP pipes may cause inflow of liquid from the tank, a metallic shutoff valve operable from above the bulkhead deck is to be fitted at the bulkhead or deck.

13 Application of Fire Protection Coatings

Where required by fire endurance criteria in Subsection 2/27, fire protection coatings are to be applied on the joints after performing hydrostatic pressure tests of the piping installation (see Section 10). The fire protection coatings are to be applied in accordance with the Manufacturer's recommendations, using a procedure approved in each particular case.

SECTION 4 Manufacturing

Preferably, the Manufacturer is to have a quality system and be certified in accordance with 4-1-1/3.5.2 of the ABS *Steel Vessel Rules* or ISO 9001. The quality system is to consist of elements necessary to ensure that pipes and components are produced with consistent and uniform mechanical and physical properties in accordance with the applicable requirements specified in this Guide or recognized standards, and is to include the following tests:

i) Samples of pipe are to be tested to determine the short-term and long-term hydrostatic design strength. These samples are to be selected randomly from the production facilities.

ii) For piping that requires fire endurance testing and flame spread testing, representative samples of pipe are to be tested to verify their performances.

iii) For piping that is required to be electrically conductive, representative samples of pipe are to be tested to determine electrical resistance per unit length.

iv) Random samples of pipe are to be tested to determine the suitability of its external corrosion barrier.

If the manufacturer does not have a certified quality system, the tests listed above will be required using samples from each batch of pipes being supplied for use aboard the facility.

Regardless of whether the Manufacturer has a certified quality system, for piping installations with a pressure rating above 32 bar (32 kgf/cm, 464 psi), each length of pipe is to be tested at the Manufacturer's production facility (shop test) to a hydrostatic pressure not less than 1.5 times the maximum allowable internal pressure of the pipe (see Subsection 2/1). For systems at or below 32 bar (32 kgf/cm, 464 psi), 5% or a selection satisfactory to the Surveyor is to be tested at the Manufacturer's production facility (shop test) to a hydrostatic pressure not less than 1.5 times the maximum allowable internal pressure of the pipe (see Subsection 2/1).

SECTION 5 Pipe Bonding Procedure Qualification

1 Procedure Qualification Requirements

1.1 Joint Bonding Parameters

To qualify joint bonding procedures, the tests and examinations specified herein are to be successfully completed. The procedure for making bonds is to include the following:

i) Materials used

ii) Tools and fixtures

iii) Environmental requirements

iv) Joint preparation requirements

v) Cure temperature

vi) Dimensional requirements and tolerances

vii) Test acceptance criteria for the completed assembly

1.3 Re-qualification

Any change in the bonding procedure that will affect the physical and mechanical properties of the joint will require the procedure to be re-qualified.

3 Procedure Qualification Testing

3.1 Test Assembly

A test assembly is to be fabricated in accordance with the procedure to be qualified and is to consist of at least one pipe-to-pipe joint and one pipe-to-fitting joint. When the test assembly has been cured, it is to be subjected to a hydrostatic test pressure at a safety factor of 2.5 times the design pressure of the test assembly for not less than one hour. No leakage or separation of joints is to be allowed. The test is to be conducted so that the joint is loaded in both the longitudinal and circumferential directions.

3.3 Pipe Size

Selection of the pipes used for test assembly is to be in accordance with the following:

i) When the largest size to be joined is 200 mm (8 in.) in nominal outside diameter or smaller, the test assembly is to be the largest pipe size to be joined.

ii) When the largest size to be joined is greater than 200 mm (8 in.) in nominal outside diameter, the size of the test assembly is to be either 200 mm (8 in.) or 25% of the largest piping size to be joined, whichever is greater.

3.5 Bonding Operator Qualification

When conducting performance qualifications, each bonder and each bonding operator are to make up test assemblies, the size and number of which are to be as required above.

SECTION 6 Tests by Manufacturer – Fire Endurance Testing of FRP Piping in Dry Condition (For Level 1 and Level 2)

1 Test Method

1.1 Furnace Test Temperature

The specimen is to be subjected to a furnace test with fast temperature increase similar to that likely to occur in a fully developed liquid hydrocarbon fire. The time/temperature is to be as follows:

i)	At the end of 5 minutes	945°C (1733°F)
ii)	At the end of 10 minutes	1033°C (1891°F)
iii)	At the end of 15 minutes	1071°C (1960°F)
iv)	At the end of 30 minutes	1098°C (2008°F)
v)	At the end of 60 minutes	1100°C (2012°F)

1.3 Furnace Temperature Control

The accuracy of the furnace control is to be as follows:

i) During the first 10 minutes of the test, variation in the area under the curve of mean furnace temperature is to be within ±15% of the area under the standard curve.

ii) During the first 30 minutes of the test, variation in the area under the curve of mean furnace temperature is to be within ±10% of the area under the standard curve.

iii) For any period after the first 30 minutes of the test, variation in the area under the curve of mean furnace temperature is to be within ±5% of the area under the standard curve.

iv) At any time after the first 10 minutes of the test, the difference in the mean furnace temperature from the standard curve is to be within ±100°C (±180°F).

1.5 Furnace Temperature Measurement

The locations where the temperatures are measured, the number of temperature measurements and the measurement techniques are to be approved by ABS.

3 Test Specimen

3.1 Pipe Joints and Fittings

The test pipe is to be prepared with the joints, fittings and fire protection coatings, if any, intended for use in the proposed application. All joint types are to be tested, as they are the primary points of failure.

It is recognized that the joint may be the primary point of failure and therefore a straight pipe-to-pipe joint may be considered representative of all bends, elbows and tees of equal or greater wall thickness, provided the construction and constituent materials are the same. If only a straight pipe-to-pipe joint is tested, then both the joint and a straight section of pipe are to be included in the test and exposed to the test conditions.

3.3 Number of Specimens

The number of specimens is to be sufficient to test typical joints and fittings, including joints between non-metal and metal pipes and metal fittings to be used. The requirements in 7/3.5 may be used, subject to the review and approval of ABS.

3.5 End Closure

The ends of the specimen are to be closed. One of the ends is to allow pressurized nitrogen to be connected. The pipe ends and closures may be outside the furnace.

3.7 Orientation

The general orientation of the specimen is to be horizontal, and it is to be supported by one fixed support, with the remaining supports allowing free movement. The free length between supports is not to be less than eight times the pipe diameter.

3.9 Insulation

Most materials will require a thermal insulation to pass this test. The test procedure is to include the insulation and its covering.

3.11 Moisture Condition of Insulation

If the insulation contains or is liable to absorb moisture, the specimen is not to be tested until the insulation has reached an air dry condition, defined as equilibrium with an ambient atmosphere of 50% relative humidity at 20 ± 5°C (68 ± 9°F). Accelerated conditioning is permissible, provided the method does not alter the properties of the component material. Special samples are to be used for moisture content determination and conditioned with the test specimen.

These samples are to be so constructed as to represent the loss of water vapor from the specimen having similar thickness and exposed faces.

5 Test Condition

A nitrogen pressure inside the test specimen is to be maintained automatically at 0.7 ± 0.1 bar (0.7 ± 0.1 kgf/cm^2, 10 ± 1.5 psi) during the test. Means are to be provided to record the pressure inside the pipe and the nitrogen flow into and out of the specimen in order to indicate leakage.

7 Acceptance Criteria

7.1 During the Test

During the test, no nitrogen leakage from the sample is to occur.

7.3 After the Test

After termination of the furnace test, the test specimen and its fire protective coating, if any, are to be allowed to cool to ambient temperature in still air, then tested to the maximum allowable pressure of the pipes as defined in Subsections 2/1 and 2/3. The pressure is to be held for a minimum of 15 minutes without leakage. Where practicable, the hydrostatic test is to be conducted on bare pipe (i.e., coverings and insulation removed) so that any leakage will be visible.

7.5 Alternative Tests

Alternative test methods and/or test procedures considered to be at least equivalent, including open pit testing method, may be accepted in cases where the pipes are too large for the test furnace.

SECTION 7 Tests by Manufacturer – Fire Endurance Testing of Water-filled FRP Piping (For Level 3)

1 Test Method

1.1 Burner

A propane multiple burner test with a fast temperature increase is to be used.

1.3 Pipe up to 152 mm (6 in.) OD

For piping up to and including 152 mm (6 in.) OD, the fire source is to consist of two rows of 5 burners, as shown in Section 7, Figure 1. A constant heat flux averaging 113.6 kW/m^2 (36,000 BTU/hr-ft^2) ± 10% is to be maintained 12.5 ± 1 cm (5 ± 0.4 in.) above the centerline of the burner array. This flux corresponds to a premix flame of propane with a fuel flow rate of 5 kg/hr (11 lb/hr) for a total heat release of 65 kW (3700 BTU/min.). The gas consumption is to be measured with an accuracy of at least ±3% in order to maintain a constant heat flux. Propane with a minimum purity of 95% is to be used.

1.5 Pipes more than 152 mm (6 in.) OD

For piping greater than 152 mm (6 in.) OD, one additional row of burners is to be included for each 51 mm (2 in.) increase in pipe diameter. A constant heat flux averaging 113.6 kW/m^2 (36,000 BTU/hr-ft^2) ± 10% is still to be maintained at the 12.5 ± 1 cm (5 ± 0.4 in.) height above the centerline of the burner array. The fuel flow is to be increased as required to maintain the designated heat flux.

1.7 Burner Type and Arrangement

The burners are to be of type "Sievert No. 2942" or equivalent which produces an air mixed flame. The inner diameter of the burner heads is to be 29 mm (1.14 in.). See Section 7, Figure 1. The burner heads are to be mounted in the same plane and supplied with gas from a manifold. If necessary, each burner is to be equipped with a valve to adjust the flame height.

1.9 Burner Position

The height of the burner stand is also to be adjustable. It is to be mounted centrally below the test pipe with the rows of burners parallel to the pipe's axis. The distance between the burner heads and the pipe is to be maintained at 12.5 ± 1 cm (5 ± 0.4 in.) during the test. The free length of the pipe between its supports is to be 0.8 ± 0.05 m (31.5 ± 2 in.). See Section 7, Figure 2.

3 Test Specimen

3.1 Pipe Length

Each pipe is to have a length of approximately 1.5 m (5 ft).

3.3 Pipe Joints and Fittings

The test pipe is to be prepared with the joints, fittings and fire protection coatings, if any, intended for use in the proposed application. All joint types are to be tested, as they are the primary points of failure.

It is recognized that the joint may be the primary point of failure and therefore a straight pipe-to-pipe joint may be considered representative of all bends, elbows and tees of equal or greater wall thickness, provided the construction and constituent materials are the same. If only a straight pipe-to-pipe joint is tested, then both the joint and a straight section of pipe are to be included in the test and exposed to the test conditions.

3.5 Number of Specimens

The number of pipe specimens is to be in accordance with Section 7, Table 1. An alternative to this table may be presented to ABS, supported by a predictive model to prove it is sufficient to test all typical joints and fittings, including joints between the FRP and metal pipes, if any. Any alternate is to be reviewed and accepted by ABS.

TABLE 1
Qualification of Piping installations of Different Sizes

Size Tested mm (in.)	*Approved Minimum Size mm (in.)*	*Approved Maximum Size mm (in.)*
0 to 50 (0 to 1.97)	Size Tested	Size Tested
>50 to 152 (>1.97 to 5.98)	Size Tested	152 (5.98)
>152 to 300 (>5.98 to 11.8)	Size Tested	300 (11.8)
>300 to 600 (>11.8 to 23.6)	Size Tested	600 (23.6)
>600 to 900 (>23.6 to 35.4)	Size Tested	900 (35.4)
>900 to 1200 (>35.4 to 47.2)	Size Tested	1200 (47.2)

3.7 End Closure

The ends of each pipe specimen are to be closed. One of the ends is to allow pressurized water to be connected.

3.9 Moisture of Insulation

If the insulation contains or is liable to absorb moisture, the specimen is not to be tested until the insulation has reached an air dry condition, defined as equilibrium with an ambient atmosphere of 50% relative humidity at 20 ± 5°C (68 ± 9°F). Accelerated conditioning is permissible, provided the method does not alter the properties of the component material. Special samples are to be used for moisture content determination, and conditioned with the test specimen.

These samples are to be so constructed as to represent the loss of water vapor from the specimen having similar thickness and exposed faces.

3.11 Orientation

The pipe samples are to rest freely in a horizontal position on two V-shaped supports. The friction between pipe and supports is to be minimized. The supports may consist of two stands, as shown in Section 7, Figure 2.

3.13 Relief Valve

A relief valve is to be connected to one of the end closures of each specimen.

5 Test Conditions

5.1 Sheltered Test Site

The test is to be carried out in a sheltered test site in order to prevent any draft influencing the test.

5.3 Water-filled

Each pipe specimen is to be completely filled with de-aerated water to exclude air bubbles.

5.5 Water Temperature

The water temperature is not to be less than 15°C (59°F) at the start, and is to be measured continuously during the test. The water is to be stagnant and the pressure maintained at 3 ± 0.5 bar (3.1 ± 0.5 kgf/cm^2, 43.5 ± 7.25 psi) during the test.

7 Acceptance Criteria

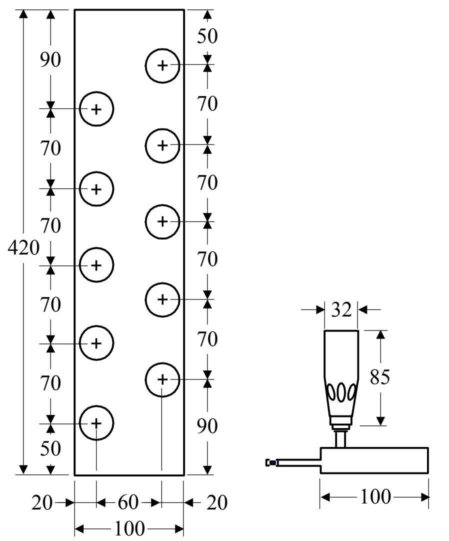
7.1 During the Test

During the test, no leakage from the sample(s) is to occur, except that slight weeping through the pipe wall may be accepted.

7.3 After the Test

After termination of the burner test, the test specimen and its fire protective coating, if any, are to be allowed to cool to ambient temperature, and then tested to the maximum allowable pressure of the pipes as defined in Subsections 2/1 and 2/3. The pressure is to be held for a minimum of 15 minutes without significant leakage [i.e., not exceeding 0.2 liters/min. (0.05 gpm)]. Where practicable, the hydrostatic test is to be conducted on bare pipe (i.e., coverings and insulation removed) so that any leakage will be visible.

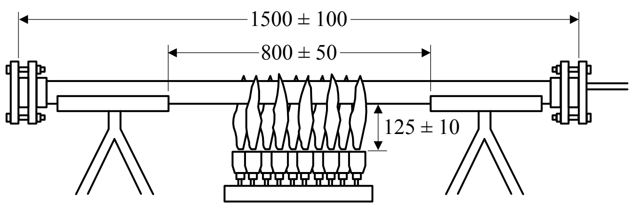
FIGURE 1
Fire Endurance Test Burner Assembly



a) Top View

b) Side View of one Burner

FIGURE 2
Fire Endurance Test Stand with Mounted Sample



SECTION 8 Tests by Manufacturer – Wet/Dry Fire Endurance Testing of FRP Piping Used in Deluge System (For Level 3 Modified Test – Level 3 WD) (Adopted from USCG PFM 1-98)

The wet/dry fire endurance testing is to consist of conducting the Level 3 fire endurance testing specified in Section 7 with the following modifications:

i) For the first five (5) minutes of the test, the piping is to be maintained in the dry condition at atmospheric pressure in lieu of containing stagnant water.

ii) After completion of the first five (5) minutes of the test, the pipe specimen is to be completely filled with flowing water.

iii) Air is to be bled from the opposite end of the piping via a test connection until a steady flow of water at the specified flow rate and pressure is observed.

iv) The flow rate should not exceed the minimum pressure and flow rate that will be observed at the hydraulically most remote nozzle of the specific deluge system installation. The elapsed time between first introducing water to the test specimen until the specified flow rate and pressure is obtained is not to exceed one minute. Testing at the specified flow rate and pressure will qualify the piping for all flow rates greater than that specified in the test.

v) The total test time including dry and wet time shall be 30 minutes.

All other requirements of Level 3 testing are to be followed without deviation.

SECTION 9 Tests by Manufacturer – Flame Spread

Flame spread of FRP piping is to be determined by IMO Resolution A.653(16), entitled "Recommendation on Improved Fire Test Procedures for Surface Flammability of Bulkhead, Ceiling, and Deck Finish Materials", with the following modifications:

i) Tests are to be performed on each pipe material and size.

ii) The test sample is to be fabricated by cutting pipes lengthwise into individual sections and assembling the sections into a test sample as representative as possible of a flat surface. A test sample is to consist of at least two sections. The test sample is to be at least 800 ± 5 mm (31.5 ± 0.2 in.) long. All cuts are to be made normal to the pipe wall.

iii) The number of sections that must be assembled to form a test sample is to correspond to the nearest integer number of sections which makes up a test sample with an equivalent linearized surface width between 155 mm (6 in.) and 180 mm (7 in.). The surface width is defined as the measured sum of the outer circumference of the assembled pipe sections that are exposed to the flux from the radiant panel.

iv) The assembled test sample is to have no gaps between individual sections.

v) The assembled test sample is to be constructed in such a way that the edges of two adjacent sections coincide with the centerline of the test holder.

vi) The individual test sections are to be attached to the calcium silicate backing board using wire (No. 18 recommended) inserted at 50 mm (2 in.) intervals through the board and tightened by twisting at the back.

vii) The individual pipe sections are to be mounted so that the highest point of the exposed surface is in the same plane as the exposed flat surface of a normal surface.

viii) The space between the concave unexposed surface of the test sample and the surface of the calcium silicate backing board is to be left void.

ix) The void space between the top of the exposed test surface and the bottom edge of the sample holder frame is to be filled with a high temperature insulating wool if the width of the pipe segments extend under the side edges of the frame holding the sample.

SECTION 10 Testing Onboard

1 Documentation and Receiving Inspection

The following information is to be made available by the Manufacturer to the users:

- Quantity and description of components and spools
- Pressure ratings of components and spools
- Nominal dimensions and overall dimensions of components and spools
- System drawings identifying spools and site weld locations
- Any installation requirements for the components and spools
- Any handling and storage requirements for the components and spools
- Any special requirements for the components and spools

All piping components are to be visually inspected according to the requirements in this Section. Bonding kits are to be inspected to ensure that all the necessary materials are available, that the kits are in good condition and that the kits are stored properly prior to usage.

3 Handling and Storage

FRP piping components can be susceptible to mechanical damage due to impact and improper handling. All personnel involved in handling and storage are to be properly trained.

Lifting, loading, unloading and storage are to be performed in accordance with procedures agreed upon between ABS, the Manufacturer and the installer. Neither chains nor steel wires are to be used for handling. Steel clamps are to be used only when proper padding or protection is provided between the steel clamp and the FRP pipe.

5 Visual Inspection

Section 10, Table 1 is to be used for visual inspection acceptance criteria and corrective action.

If discrepancies or disagreements occur over the visual inspection requirements, an independent third party acceptable to the Surveyor and installer may perform a second inspection and recommend a corrective action.

TABLE 1
Defects Acceptance Criteria and Corrective Action

Name	*Definition*	*Criteria*	*Corrective Action*
Air bubble	Air entrapment within and between the plies of reinforcement, usually spherical in shape. Normally found at or near the inner surface of the laminate.	Diameter of bubble is to be less than or equal to 1.5 mm ($^1/_{16}$ in.). If it is larger that 1.5 mm ($^1/_{16}$ in.), no more than 2 bubbles per square inch are allowed.	Bubbles $^1/_{16}$ in. diameter or smaller may be accepted as-is. Larger bubbles shall be rejected or repaired.
Burn (delamination)	Thermal decomposition evidenced by distortion or discoloration of the laminate.	Acceptable if burn is not in the structural layer.	If burn is not in the structural layer, then either accept as-is or resin-coat the area. If burn is in the structural layer, then either remove (by grinding) the damaged area or reapply a laminate to maintain structural integrity or reject the part.
Chip	A small piece broken off an edge or surface. If reinforcing fibers are broken, then refer to a "crack".	Area of damage must be less than 10 × 10 mm ($^3/_8$ in. × $^3/_8$ in.).	Either resin coat area or lightly grind area and then reapply CSM and/or veil.
Crack	An actual separation of the laminate visible on opposite surfaces and extending through the thickness.	Acceptable if crack is only a surface crack and does not extend below the surface coating.	For surface cracks, either accept as-is or re-coat. For deeper cracks, cracks should be filled with adhesive. If structural integrity is in question (crack extends to depth of filament winding or woven roving), part should be rejected.
Crazing	Fine hairline cracks, normally at or underneath the surface.	Acceptable up to 25 mm (1 in.) in length.	Accept as-is for cracks up to 25 mm (1 in.) in length. For longer cracks, lightly grind the surface to remove the crack and re-surface with veil and/or resin.
Dry spot	Area of incomplete surface film where the reinforcement has not been wetted with resin, leaving exposed glass reinforcement	None permitted.	Dry spot may be resin coated, but must be visually inspected after cure.
Fracture	Rupture of laminate surface with or without complete penetration. Majority of fibers broken.	None permitted.	Damaged area to be removed by grinding and a laminate to be reapplied to maintain structural integrity. Fractures discovered as a result of hydrotesting that can not be repaired shall be rejected.
Impact Damage	Light area with or without broken fibers.	Areas larger than 10 mm ($^3/_8$ in.) diameter are not permitted.	Resin coat area or lightly grind area and reapply CSM[1] and/or veil. Larger areas of damage may be surface prepped and wrapped with a laminate of CSM[1] (and WR[2] if necessary).
Incorrect Laminate Sequence	Laminate sequence of part does not match the specification.	Laminate sequence must meet or exceed the required minimum for the application.	Laminate sequence that is deemed inadequate for the application shall either be reinforced with the necessary additional plies or shall be removed and replaced.
Incorrect Spool Dimensions	Incorrect dimensions or misaligned components.	Overall system dimensions must be maintained. Misaligned parts must not be overstressed.	If possible, make up difference elsewhere in the system. Otherwise, components may have to be removed and re-welded.

TABLE 1 (continued)
Defects Acceptance Criteria and Corrective Action

Name	*Definition*	*Criteria*	*Corrective Action*
Lack of Adhesive	Bonded area has lack of adhesive which creates a dis-bondment between the parts being joined.	Bond area must be adequate for the design conditions.	When the de-bonded area is greater than 30% of the total bond area, the part is to be rejected. Smaller de-bonded areas may be evaluated for overall integrity and either accepted or rejected.
Low Barcol Hardness	Barcol hardness reading below the required minimum.	Barcol hardness must be at or above the required minimum.	If after 24 hours Barcol hardness is not achieved, the part may be allowed to cure at ambient temperature for another 24 hours or may be post-cured to accelerate the cure. If after 48 hours Barcol hardness is not achieved, the part shall be rejected.
Pit (Pinhole)	Small crater in the inner surface of a laminate, with its width approximately of the same order of magnitude as its depth.	Diameter of pits to be less than 0.8 mm ($^1/_{32}$ in.) and depth to be less than the thickness of the liner.	If there are no damaged fibers and pits meet the criteria, then accept as-is. Otherwise, part may need to be rejected.
Restriction (Excess Adhesive)	Excess adhesive on the internal wall of a pipe/fitting causing a restriction.	Any obstruction shall be less than 5% of the inside diameter and no more than 10 mm in height.	If accessible, excess adhesive is to be carefully ground. If not accessible, part is to be removed and replaced.
Scratch	Small mark caused by improper handling, storage, and/or transportation. If reinforcing fibers are broken, then damage is considered a "Crack".	Area of damage shall not affect the fibers and shall not be larger than 10 × 10 mm ($^3/_8$ in. × $^3/_8$ in.)	If damaged area is $^3/_8$ in. × $^3/_8$ in. or smaller, then accept as-is. Larger areas with only surface damage (no fiber damage) shall be resin coated if coating has been damaged. Larger areas with fiber damage shall be lightly ground and reapplied with CSM(1) and/or WR(2).
Uneven Wall Thickness for Adhesive Bond	After surface preparation, parts to be bonded have an uneven wall thickness possibly causing air voids in the bond.	Allowable eccentricity is 0.002 × ID, but no more than 0.3 mm	Part shall be rejected and replaced.
Weeping	Minor liquid penetration through the laminate during pressure testing.	None permitted.	Area shall either be lightly ground and then reapplied with a laminate of CSM(1) and WR or damaged part shall be removed and replaced.
Weld Sparks	Minor breakdown of outer surface due to effects of close-proximity welding.	See "Scratch".	See "Scratch".

Notes:

1 CSM – Chopped Strand Mat

2 WR – Woven Roving

3 For defects such as cracks, pits, and scratches, if a number of these defects occur in a small area, the corrective action may be modified to the satisfaction of the Surveyor to take this into account.

7 Resin/Adhesive Degree of Cure

The degree of cure of resins and adhesives is to be checked to the satisfaction of the Surveyor. The frequency of testing is to be agreed between the installer and the Surveyor.

The degree of cure is to be determined in accordance with one of the following methods:

i) Glass transition temperature (T_g) by DSC (differential scanning calorimetry) according to ISO11357-2 or by HDT according to ASTM E2092. The T_g is to be 30°C above the maximum design temperature when measured according to DSC and 20°C above the maximum design temperature when measured according to HDT.

ii) Residual styrene monomer content testing according to ISO 4901. The residual styrene content is to be no more than 2% (mass fraction) of the resin weight.

iii) Barcol hardness testing according to ASTM D2583. The Barcol hardness readings are to be at least 90% of the value specified by the manufacturer or adhesive/resin supplier.

9 Documentation of Site Bonding

All pipes, fittings, flanges, spools and related items are to be installed by qualified FRP pipefitters or with qualified supervision. All bonding is to be performed by qualified FRP bonders.

Documentation of the qualification of supervisors, pipefitters and bonders is to be made available to the Surveyor.

The following documentation is to be maintained on each site weld during the installation process:

- Identification of bonder(s) who performed the site weld bonding
- Identification of inspector(s) who inspected the site weld bonding
- Acceptance of visual inspection of the site bonding
- Acceptance of the degree of cure of the site bonding
- Traceability of the resin/adhesive used for the site bonding

11 Repair Methods

Section 10, Table 1 is to be used to determine any necessary repairs during the installation phase of the project.

13 System Hydrostatic Test

Piping installations are to be subjected to a hydrostatic test pressure of not less than 1.5 times the design pressure, but no more than 1.5 times the rated pressure of the lowest rated component in the system, to the satisfaction of the Surveyor. For piping required to be electrically conductive, grounding (earthing) is to be checked and random resistance testing is to be conducted to the satisfaction of the Surveyor.

15 Maintenance

15.1 Impact Damage

FRP piping is normally more susceptible to impact damage than traditional carbon steel piping because of the relative brittleness of the resin. Lower impact energy levels may cause surface cracks or deeper cracks that would not be experienced in carbon steel systems. Extra care is to be taken with thin wall FRP piping (3 mm or less) that does not offer any significant resistance to impact damage.

15.3 Erosion

Particulates in the fluid may cause erosion of the piping from inside. Generally, higher particulate contents, larger particulate sizes and higher fluid velocities all increase the potential for erosion. Visual and/or ultrasonic inspections may be used to evaluate the effect of erosion on an FRP piping installation. If there is a reduction of structural wall thickness of more than 20% of the original structural wall thickness, then replacement of the affected section is to be considered. Reductions of less than this amount may be accepted, but future monitoring may be required.

15.5 Earthing Cables

Earthing cables connecting electrically conductive FRP systems to ground may be subject to corrosive attack in a salt air environment. Although the required maximum resistance to ground can be very high (usually 10^6 ohms from any point to ground), corrosive attack on the earthing cables can affect this resistance. Visual inspection of the earthing connections or a conductivity test using a meghommeter may be used to determine the effectiveness of the connection. If the measured resistance is below the accepted value, then the earthing cable is to be repaired or replaced.

15.7 Chalking/"Fiber Bloom"

In FRP systems with no external corrosion barrier or where there has been damage to the external corrosion barrier, exposure to UV rays can affect the surface of the FRP piping. One phenomenon known as "fiber blooming" (which is a whitening of the surface glass fibers) occurs when this happens. Piping installations with effective external corrosion barriers are normally protected from this effect. If chalking or fiber blooming has occurred and the effect has penetrated the outer surface layer of the piping, then consideration is to be given to repairing or replacing the affected piping.

15.9 Scale Deposits

In some water systems, particularly salt water systems, there can be a scale buildup on the inside surface of the FRP piping over time. Normally, this has a greater potential to occur when the piping is exposed to stagnant water for long periods of time (several weeks or more). Systems operating even at very low velocities are less likely to have scale buildup. FRP is normally inert to marine life in that it offers neither nourishment nor toxic effects. Visual inspection (via measurement of flow rate) may be used to determine if scale buildup is occurring. If there is a reduction in inside diameter of more than 10 mm or 5%, then consideration is to be given to cleaning the piping installation. Mechanical methods involving water jetting may be considered. Hypochlorination by electrolytic decomposition or continuous chlorination may be considered to prevent scale buildup.

15.11 System Failures

System failures, such as burst pipes, can occur if the FRP piping installation is subjected to pressures, temperatures or other loads above its design limits. Any failures of this type are to be replaced.

15.13 Flange Damage/Cracks

FRP flanges can be susceptible to cracks. These cracks can develop due to a number of reasons, but are usually due to overtorqueing of the flanges. There is a greater potential for this to occur against raised-face flanges. Visual inspection is to be used to determine the presence of any cracks. If any leakage occurs, the flange is to be repaired or replaced.

APPENDIX 1 References

Standards/codes acceptable to ABS are not limited to the following references.

When updates of the referenced documents are available, they are as far as possible to be used.

Which standards/codes to be followed during design, manufacturing, transportation, storage, installation, testing, operation, amendment, decommission, etc. is generally to be agreed upon between Local Authorities, Owners, Operators, Clients and Contractors.

ABS claims the right to reject documents, procedures, etc. where standards/codes are judged misused, for instance, by "shopping around".

ABS
American Bureau of Shipping

ABS Plaza, 16855 Northchase Drive,
Houston, TX 77060, USA

Code No.	*Year*	*Title*
Steel Vessel Rules	2004	Rules for Building and Classing Steel Vessels
MODU Rules	2001	Rules for Building and Classing Mobile Offshore Drilling Units
Facilities Guide	2000	Guide for Building and Classing Facilities on Offshore Installations

ASTM
American Society for Testing and Materials

100 Barr Harbor Drive, PO Box C700
West Conshohocken, PA, 19428-2959 USA

Code No.	*Year*	*Title*
ASTM D 256	2004	Standard Test Methods for Determining the Izod Pendulum Impact Resistance of Plastics
ASTM D 257	1999	Standard Test Methods for DC Resistance or Conductance of Insulating Materials
ASTM D 635	2003	Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position
ASTM D 790	2003	Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials
ASTM D 1599	1999	Standard Test Method for Resistance to Short-Time Hydraulic Failure Pressure of Plastic Pipe, Tubing, and Fittings
ASTM D 2105	2001	Standard Test Method for Longitudinal Tensile Properties of Fiberglass (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Tube
ASTM D 2444	1999	Standard Test Method for Determination of the Impact Resistance of Thermoplastic Pipe and Fittings by Means of a Tup (Falling Weight)
ASTM D 2583	2001	Standard Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor
ASTM D 2925	2001	Standard Test Method for Beam Deflection of Fiberglass (Glass-Fiber-Reinforced Thermosetting Resin) Pipe Under Full Bore Flow
ASTM D 2992	2001	Standard Practice for Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings
ASTM E 2092	2004	Standard Test Method for Distortion Temperature in Three-Point Bending by Thermomechanical Analysis

ASCE
American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia 20191

Code No.	*Year*	*Title*
ASCE 7-88	1992	Minimum Design Loads for Buildings and Other Structures

BSI
British Standards Institute
2 Park Street
London, W18 2BS, United Kingdom

Code No.	*Year*	*Title*
BS 7159	1989	Code of practice for design and construction of glass-reinforced plastics (GRP) piping systems for individual plants or sites

IMO
International Maritime Organization
4 Albert Embankment
London SE1 7SR, United Kingdom

Code No.	*Year*	*Title*
MSC.61 (67)		International Code for Application of Fire Test Procedures
Resolution A.653 (16)		Recommendation on improved fire test procedures for surface flammability of bulkhead, ceiling and deck finish materials
Resolution A.753 (18)		Guidelines for the application of plastic pipes on ships
Resolution A.754 (18)		Recommendation on fire resistance tests for "A", "B" and "F" class divisions

ISO
International Organization for Standardization
1, rue de Varembé, Case postale 56
CH-1211 Geneva 20, Switzerland

Code No.	*Year*	*Title*
ISO 75-3	2004	Plastics – Determination of temperature of deflection under load – Part 3: High-strength thermosetting laminates and long-fibre-reinforced plastics
ISO 4901	1985	Reinforced plastics based on unsaturated polyester resins – Determination of residual styrene monomer content
ISO 11357-2	1999	Plastics – Differential scanning calorimetry (DSC) – P art 2: Determination of glass transition temperature
ISO 14692	2002	Petroleum and natural gas industries – Glass-reinforced plastics (GRP) piping
ISO 9001	2000	Quality management systems – Requirements